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LIMITATIONS AND EFFECTS OF WASTE DISPOSAL ON AN OCEAN SHELF

FLORIDA OCEAN SCIENCES INSTITUTE

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

DECEMBER 1971

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Florida Ocean Sciences Institute, 1605 S. E. Third Court
Deerfield Beach, Florida 33441

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10 Author(s)
Lukin, Lawrence D.
Lee, Thomas N.
Lackey, James B.
McGuire, James B.
Davis, Terry L.
Barry, James

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27 Abstract
Biological, chemical, and oceanographic parameters of coastal waters off southeast Florida were investigated over a three year period to determine the effects of marine waste disposal from the untreated outfall at Pompano. The macroscopic benthos, and microscopic organisms of the sediment-water, interface and of the planktonic community were surveyed. Numbers of microbiotic organisms were consistently low in coastal waters, with numbers greater than 500 per ml being rare. A pile of sand and blackened organic material forms beneath the outfall in which only one type of pollution resistant sludge worm was found. Temperature, salinity, and current observations reveal that coastal circulation is dominated by the Florida Current. Large fluctuations in coastal currents are produced by east-west meanderings of the western edge of the Florida Current, and current reversals are produced by cyclonic spin-off eddies. Dye tracing techniques were used to determine the spacial and temporal sewage field concentrations. Prevailing onshore winds cause the surface sewage plumes, containing high concentrations of coliform bacteria, to travel toward highly populated bathing beaches. Treatment for bacteria kill is recommended for all southeast Florida outfalls. A method for determining the percent treatment for each outfall is given.

Abstractor Joseph J. Richter
Institution Florida Ocean Sciences Institute

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LIMITATIONS AND EFFECTS
OF
WASTE DISPOSAL ON AN OCEAN SHELF

by

Florida Ocean Sciences Institute
1605 S. E. Third Court
Deerfield Beach, Florida 33441

for the

Environmental Protection Agency

Demonstration Project Grant 16070 EFG

December 1971

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EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The biological, chemical and physical oceanographic properties of the coastal waters off Pompano, Boca Raton and Delray, Florida were investigated over a three year study to determine the effects of marine waste disposal from the untreated outfalls at Pompano and Delray and the planned outfall for Boca Raton. The macroscopic benthic communities and microbiotic organisms of the sediment-water interface and of the free drifting plankton were surveyed. The number of microbiotic organisms were consistently low in coastal waters. Blooms with numbers greater than 500 per ml were rare. A pile of sand and blackened organic material, approximately 3 feet high, 50 feet long and 30 feet wide forms beneath the outfall. Only one pollution resistent sludge worm can survive in this area. The periphery of the pile, stretching 100 feet north-south and 50 feet east-west, is restrictive to the number of species which can survive. A large number of current cross, temperature, salinity and current meter observation reveal that due to the extreme narrowness of the Continental Shelf, coastal circulation is dominated by the Florida Current. Large fluctuations in coastal currents are produced by east-west meandering of the western edge of the Florida Current. Current reversals are produced by cyclonic spin-off eddies which frequently pass through and flush the coastal waters. These effects mask the periodic, diurnal and semi-diurnal tidal fluctuations. Fluorometry, dye tracing techniques were used to determine the spacial and temporal sewage field concentrations. Prevailing onshore winds cause the surface sewage plumes, containing high concentrations of coliform bacteria, to travel towards the highly populated bathing beaches. Treatment for bacteria kill is recommended for all southeast Florida outfalls. A method for determining the percent treatment for each outfall is given. This report was submitted in fulfillment of Demonstration Project Grant WPD 165-01 (R-1) -67 under the sponsorship of the Water Quality Office, Environmental Protection Agency.

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SECTION I

CONCLUSIONS

The following statements are a summary of the conclusions reached in each section of this report. For more detailed information one is referred to the conclusion segment and body of each section of this document:

1. Zonation and species diversity of benthic organisms perpendicular to shore are due primarily to bottom stability which is controlled by the north-south configuration of the main reef 1 to 1.5 nautical miles offshore of the main reef, in approximately 60 feet of water.

2. The Pompano outfall region consists of three zones:

   (1) Polluted: A pile of sand and blackened organic material, approximately 3 feet high, 50 feet long and 30 feet wide which forms beneath the outfall. Only one pollution resistent sludge worm can survive in this area.

   (2) Tolerant: The periphery of the polluted zones, stretching 100 feet north-south and 50 feet east-west from the outfall and is restrictive to the number of species which can survive.

   (3) Unaffected: The area outside the periphery which does not inhibit benthic communities.

3. The number of planktonic organisms were consistently low in the coastal water near Pompano and Delray outfalls. No noticeable fertilization effects were found. Planktonic blooms with numbers greater than 500 per ml were rare.

4. Due to the extreme narrowness of the Continental Shelf (1 to 1.5 nautical miles), coastal circulation and exchange processes are dominated by the Florida current.

5. Large fluctuations in speed and direction of coastal currents are produced by east-west meandering of the western edge of the Florida current.

6. Resultant currents are predominately in the north-south direction with north currents occuring approximately 60% of the time and south currents 30%.

7. Current reversals are produced by cyclonic eddies which spin off the Florida current and travel northward through the coastal waters.

8. Periodic diurnal and semi-diurnal tidal currents are found to be of equal magnitude and are dominated by fluctuations of the Florida current.

9. Spin-off eddies behave as major flushing mechanisms for the coastal waters.

10. The residence time of coastal water is estimated from the number and duration of spin-off eddies to be on the order of one week.

11. Shelf water is strongly stratified in late spring and early summer. The combination of stable stratification and strong currents can mix discharged waste below the surface preventing the effluent from surfacing.

12. During the remainder of the year the effluent will rise to the surface forming a "boil" and then move horizontally with the resultant surface current forming a "plume".

13. Ocean outfalls along southeast Florida do not discharge "into the Gulfstream" but rather into a narrow strip of coastal water which is directly under the influence of the Gulfstream.

14. The predominance of onshore winds produces a shoreward component in the resultant surface currents. This causes the outfall plume to travel at some angle toward shore, depending upon the relative strength of the wind and the longshore velocities induced by the Florida currents.

15. Disinfection of sewage effluents, untreated or treated, must be accomplished for all southeast Florida outfalls. Equations and a table summary for bacteriological kill is given in the body of the report for determining the percentage destruction of total coliforms needed for each outfall discharging at the ninety (90) foot isobath. During the period December 1 through April 30, the combination of low water temperature causing higher bacterial survival time, and prevailing on-shore winds; there may occur an intersectio of bacteriological concentrations in excess of 1000 total coliforms per 100 ml with the surf waters of our bathing beaches.

It is therefore necessary that the bacteriological kill requirements be required by regulatory agencies, with corresponding adequacy of design and operation of disinfection equipment.

SECTION II

RECOMMENDATIONS

Based on the findings of this study, which is centered around the Pompano ocean outfall, it is recommended that all sewage effluent being discharged into the coastal waters of southeast Florida be treated in the plant for coliform removal. This will require the engineer to re-evaluate current chlorination practices which merely control odor, and to develop new methods which will lead to effective bacterial destruction.

The results of this study show clearly that we are only beginning to understand the southeast Florida coastal exchange processes. A broader study is needed that can cover the coastal strip from Key Largo to Cape Kennedy. A network of oceanographic sensors should be deployed that can monitor such events as Florida Current meandering and the passage of spin-off eddies. A systematic sampling program as routine surveillance should be initiated to track the spatial movements of sewage effluent from all of southeast Florida's outfalls. A low budget agency surveillance program should include tracking the downstream plume with dye, and collection of samples within the plume monitored for total coliforms, phosphate, and other constituents as may be required. Samples for planktonic determinations should be taken in conjunction with the effluent tracking. Predictive hydrodynamic and convective modeling techniques should be applied to this region in order to understand the dynamics of coastal circulation and exchange processes.

This study was based on discharge of untreated effluents to the ninety (90) foot isobath. Discharge of untreated effluents into outfalls extending into deeper water, particularly beneath the semi-permanent pycnocline region, should be considered as an additional safety factor.

SECTION III

INTRODUCTION

"In Kohln, a town of monks and bones,
And pavements fang'd with murderous stones
And rags, and hags, and hideous wenches;
I counted two and seventy stenches
All well defined, and several stinks!
Ye Nymphs that reign o'er sewers and sinks.
The river Rhine, it is well known,
Doth wash you city of Cologne;
But tell me, Nymphs, what power divine
Shall henceforth wash the river Rhine?"
(Samuel Taylor Coleridge)

Even in the latter part of the 18th Century the problem of sewage waste disposal pricked man's social conscience. Engineers have devised many alternates to both the pretreatment of waste and the movement of the treated effluent to its inevitable resting place, the sea. One such alternative has been the direct discharge of waste via ocean outfall systems which, where feasible, offers definite economic advantages by eliminating various pretreatment stages and affording less hazard to the fresh waters carrying the treated effluent to its ultimate disposal point. The purpose of this project has been to determine the effects and limitations of sewage waste disposal via ocean outfall systems along Florida's lower east coast.

PROJECT OBJECTIVES

Oceanographic features of the near shore circulation were determined using the following methods: horizontal and vertical arrays of current meters and thermistors covering the study area from Pompano to Delray, Florida; and field surveys of temperature, salinity and currents. The data was analyzed manually and on the Florida Atlantic University computer to show the resulting spatial and temporal variations of velocity, temperature and salinity. The objective of the analysis of the oceanographic data was to determine the cause and effect relationships of the observed parameters and the significance of the resulting near shore features to ocean outfall disposal.

Disperions model studies were conducted with emphasis on the determination of concentration as a function of position and time. The objective of these dispersion measurements and models was to develop an understanding of the following: boil formation and dilution (initial dilution in the bouyant plume to establish concentration, c(t), and occurrence of a surface boil as a function of cross current and density stratification);

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effluent plume shape and direction (down current transport and dispersion) to establish c(x,t) and trajectory as a function of current speed and direction and density stratification; and the behavior of the concentration maximum as a function of down-stream distance. This latter will be accomplished by a continuous fluorometer measurement of dye concentration, and analysis of these measurements by application of both diffusion and stream flow models.

To then determine what effect, if any, ocean outfalls have on the surrounding benthic community, the following were done: organisms in the area of Boca Raton prior to outfall injection, and beneath the existing outfalls, were identified and keyed for pollution indicators; nutrient concentrations and organic content of core samples beneath the outfalls were determined; and sediment-water interface studies, plankton determinations, and an analysis of settleable solids beneath the outfalls were conducted.

Bacteriological samples from the fluorometer outlet at peak dye readings in the boil and downstream plume, plus samples from the sewage lift stations were collected for the purpose of making total and fecal coliform counts (using the "standard methods" MPN technique, and the parallel membrane filter-fecal coliform (M-FC) method according to the "Brezenski technique".) Additionally, the results from the dye studies, i.e., c(x,t), were compared to the bacteriological data.

The final objective of this study has been to interpret the near shore circulation features, dispersion model studies, constituents of the benthic community, and bacteriological concentrations in terms of state water quality standards.

The data collected during this study is being retained by either Florida Ocean Sciences Institute or the individual investigator responsible for the analysis. The observations are in many different forms: raw data (i.e., strip charts, log books and collected specimens;) first phase analysis such as spatial and temporal charts, plots and tables; and second phase analysis which consists of computer cards and printouts. Anyone interested in obtaining data or other information concerning this study should write to Science Coordinator Florida Ocean Sciences Institute.

SECTION IV

MACROSCOPIC BENTHIC BIOLOGY

PURPOSE OF STUDY

The macroscopic biology portion of this three-year study conducted for the Federal Water Pollution Control Administration was originally designed as a before and after survey of the reef in the vicinity of the future sewage outfall at Boca Raton, Florida. The reef survey was considered to be quantitatively and qualitatively inaccurate because of the difficulties in obtaining equal size samples, processing the rock material, and mutilation of the specimens which made identification difficult. In lieu of the reef survey, a sand survey was initiated as the sampling was relatively easy, processing was less difficult, and specimens were collected in good condition, yielding accurate and meaningful data.

The Boca Raton sand sampling program was initiated during the second year of the grant as a before and after survey of the area of possible influence from deposition of waste material from the Boca Raton outfall. In the latter part of the third year it became evident that the outfall construction would not be completed and the after portion of the survey could not be performed. In order to formulate some comparative conclusions from our studies, a sand sampling program was initiated in the area of the active Pompano Beach sewage outfall.

The purpose of this study was to determine the effects of sewage, discharged from an ocean outfall, on macroscopic marine life. The Pompano Beach outfall site was selected because it was geographically the nearest active outfall to Boca Raton and, consequently, would have similar physical oceanographic parameters and biota.

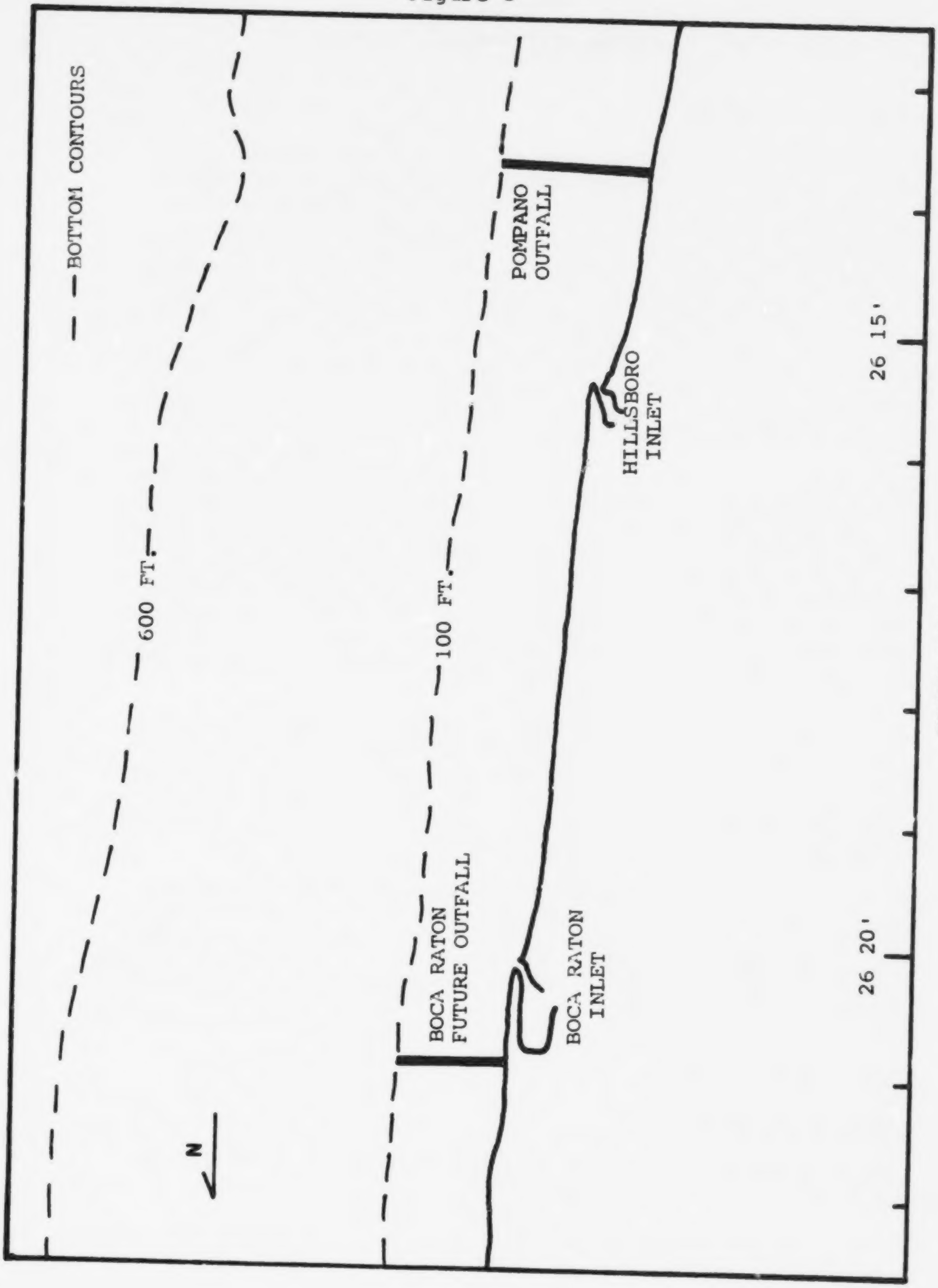
The purpose of this report is to show the difference between the macroscopic, benthic biota of two areas--Boca Raton which is relatively unaffected by outfalls, and Pompano Beach which has been subjected to the effects of sewage discharge for the past five and one-half years. These areas are shown in Figure 1.

PROCEDURES

STATION DETERMINATION

The general area selected at Boca Raton lies north and inshore of the future outfall site.

Figure 1


BOTTOM CONTOURS
600 FT.
100 FT.
POMPANO OUTFALL
HILLSBORO INLET
BOCA RATON FUTURE OUTFALL
BOCA RATON INLET
N
26 15'
26 20'
STUDY AREA

This is the area most likely to be influenced by effluent due to the predominant northerly currents, approximately sixty percent of the time.

The sampling stations at Boca Raton were plotted on a chart at three hundred foot intervals on east-west transects which extended to a distance of six thousand feet offshore (see Figure 2). Surveyor's transits located on fixed shore positions were used to position a boat over the sampling station. Citizen band radios were used for communication, and when the boat was in position, an anchored buoy was released. The sand sampling location was arbitrarily set at one foot south of the anchor or the nearest sand pocket, if the anchor was on a reef.

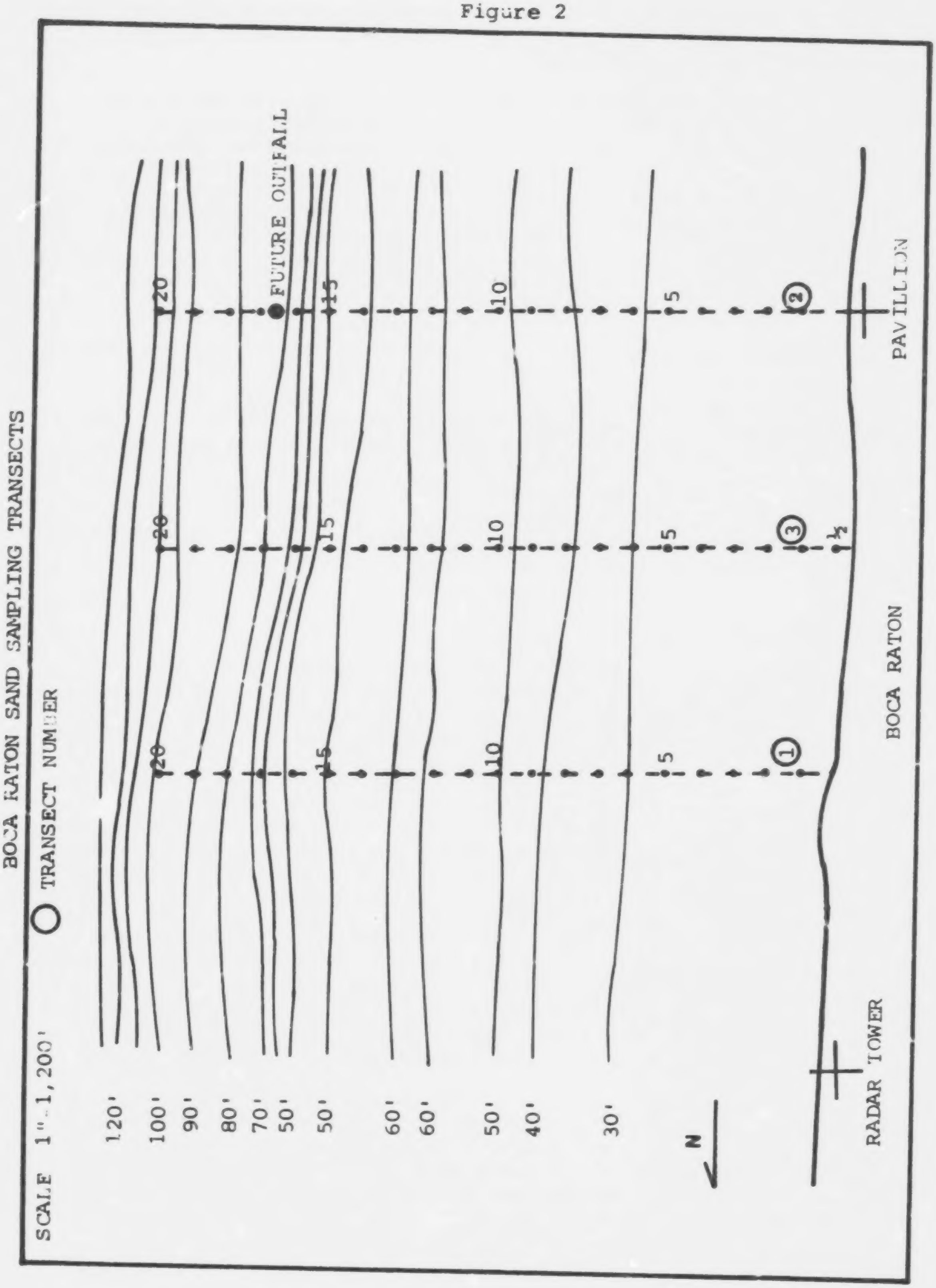
The Pompano Beach outfall region sand sampling stations were determined by scuba divers (see Figure 3). The "outfall pile" stations were located on top of the sludge pile accumulation below the end of the pipe (see Figure 4). The "outfall periphery" stations were located in the sand just beyond the pile and in front of the pipe. The fifty and one hundred foot stations located on the compass points were determined by placing a stake, with a line attached, at the end of the pipe and swimming a compass course to the length of the line.

SAMPLING METHODS

All samples were taken by a diver-biologist with a scoop and a 3100 ml container. The container was filled with bottom material from the same point to an approximate depth of five inches. On occasion, this was not possible due to the thin layer of sand covering the hard rock or an insufficient amount of material in the sand pocket. When conditions did not permit the normal sampling technique, rather than delete the station, the quantity of material was obtained by using a larger surface area, and a note was made of the sampling technique variation. The 3100 ml container was emptied underwater by inverting it inside a plastic bag. Thus, the sample was brought to the surface without any loss of material. The plastic bag also contained water which helped keep the organisms alive. Rose bengal stain was added to the sample and assimilated by the organisms, turning them pink. Their color and movement aided in locating them during processing. The color was also helpful during identification, as it made anatomical features more discernible.

The topographical features of the area, bottom composition, proximity of the station to the reef and rock outcroppings, etc., were noted. The presence and predominance of any surrounding fauna and flora were also noted. Depth of the sampling station was determined from a depth gage. This data is given in Tables 1, 2, 3, and 4.

Figure 2


BOCA RATON SAND SAMPLING TRANSECTS

SCALE 1"=1,200'
○ TRANSECT NUMBER
120'
100'
90'
80'
70'
50'
50'
60'
60'
50'
40'
30'
N
RADAR TOWER
BOCA RATON
PAVILLION
FUTURE OUTFALL
20
15
10
5
1
20
15
10
5
3
½
20
15
10
5
2

Figure 3

POMPANO BEACH OUTFALL REGION SAND SAMPLING STATIONS

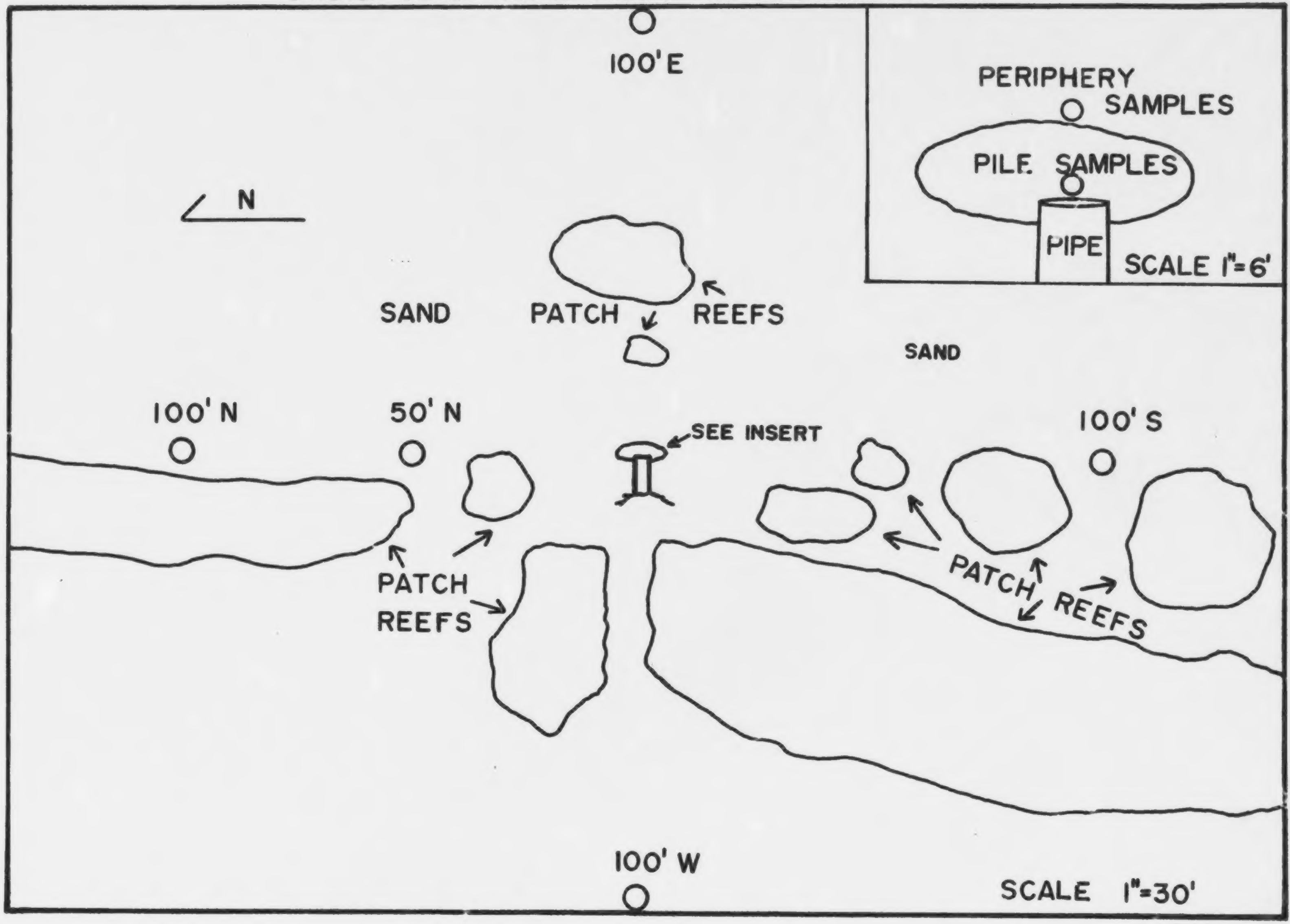

100'E
PERIPHERY
SAMPLES
PILE SAMPLES
PIPE
SCALE 1"=6'
N
SAND
PATCH
REEFS
SAND
100'N
50'N
SEE INSERT
100'S
PATCH
REEFS
PATCH
REEFS
100'W
SCALE 1"=30'

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Figure 4

Table 1
Sand Sampling Field Notes - Boca Raton Transect #1

Station	Depth	Estimate of Material Size	Algal Cover on Sand	Geological Features
1	11'	-------------	-----------	Fine sand on top of worm rock - no organisms in rock
2	15'	good bit of material over 1/12"	-----------	open sand
3	20'	very little material over 1/12"	-----------	open, fine sand
4	22'	very little material over 1/12"	-----------	open, fine sand
5	25'	very little material over 1/12"	-----------	open, fine sand
6	28'	small amount material over 1/12"	-----------	open, fine sand
7	33'	increased amount material - over 1/12"	-----------	just seaward of patch reef sand

Table 1
Sand Sampling Field Notes - Boca Raton Transect #1 (continued)

Station	Depth	Estimate of Material Size	Algal Cover on Sand	Geological Features
8	38'	increased amount material - over 1/12"	algal mat	open sand
9	42'	decreased amount material - over 1/12"	light algal mat	open sand
10	49'	material over 1/12" equals #9	heavy algal mat	open, fine sand
11	59'	increased amount material - over 1/12"	medium algal covering	flat sand
12	62'	medium amount material over 1/12"	medium algal covering	flat sand
13	60'	medium amount material over 1/12"	medium algal covering	open sand

Table 1
Sand Sampling Field Notes - Boca Raton Transect #1 (continued)

Station	Depth	Estimate of Material Size	Algal Cover on Sand	Geological Features
14	60'	approx. 60-75% material over 1/12"	light algal covering *Caulerpa* dominating	open sand
15	62'	approx. 75% material over 1/12"	----------	just inshore of reef
16	70'	approx. 30% material over 1/12"	very little algae	gulley in reef-shallow sand
17	86'	approx. 50% material over 1/12"	very little algae	patch reef area
18	100'	approx. 75% material over 1/12"	*Halimeda*, *Dictyota*, *Jania* and red filamentous	patch reef area
19	108'	approx. 50% material over 1/4"	covering of tufty red algae	loose rock and course sand

Table 1
Sand Sampling Field Notes - Boca Raton Transect #1 (continued)

Station	Depth	Estimate of Material Size	Algal Cover on Sand	Geological Features
20	115'	approx. 30% material over 1/12"	----------	loose rock and coarse sand

Table 2

Sand Sampling Field Notes - Transect #2

Station	Depth	Material Size Analysis in cm3				Algal Covering	Geological Features	Comments
		>½"	½-¼	¼-1/12"	<1/12"			
1	12'	--	4	83	3013	none	open sand	--------
2	15'	--	-	8	3092	light filamentous	open sand	--------
3	22'	--	-	12	3088	light filamentous	open sand	mounds of sand in middle crab, worm, etc.
4	25'	--	-	15	3085	light filamentous	open sand	same as above
5	27'	--	1	46	3053	medium covering of filamentous	open sand	same as above few egg masses
6	35'	--	1	34	3065	dense covering of filamentous	open sand	same as above
7	42'	--	1	15	3084	medium algal covering	open sand	--------
8	47'	11	1	17	3082	medium algal covering	open sand	--------

Table 2

Sand Sampling Field Notes - Transect #2 (continued)

		Material Size Analysis in cm3						
Station	Depth	>½"	½-¼	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
9	54'	--	1	28	3071	medium algal covering	open sand	--------
10	60'	--	1	25	3074	Medium quantity of Caulerpa and filamentous red	sand mounds circa 2 ft high	--------
11	63'	28	25	160	2887	light quantity of Caulerpa and filamentous red		--------
12	63'	1	2	61	3036	light quantity of Caulerpa and filamentous red	open sand	--------
13	64'	--	1	31	3068	Same as above	open sand	--------
14	64'	54	74	668	2304	none	just inshore of main reef in a patch reef area	

Table 2

Sand Sampling Field Notes - Transect #2 (continued)

Station	Depth	Material Size Analysis in cm3				Algal Covering	Geological Features	Comments
		>½"	½-¼"	¼-1/12"	<1/12"			
15	58	76	107	1185	1732	none	on top of reef	Sample taken in crevice about 20'SW of station-sand sufficient to taken sample in normal fashion
16	80'	260	145	415	2280	none	course sand in patch reef area approx. 20' east of main reef	difficult to obtain sample - had to use extra surface area due to thin layer of sand on top of the hard rock.
17	90'	60	19	180	2841	sparse algae population on patch reef	fine sand in patch reef area	--------

Table 2
Sand Sampling Field Notes - Transect #2 (continued)

		Material Size Analysis in cm3						
Station	Depth	>½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
18	101'	215	290	540	2055	light *Caulerpa* & *Halimeda* populations	very coarse sand with patch reef approx. 75' to the west	--------
19	118'	210	240	430	2220	small patches *Caulerpa* in the area	very coarse sand type bottom material in area with sponge and alcyonarian populations	--------
20	130'	400	288	435	1977	mats of red filamentous algae	Flat, very coarse sand bottom approx. 1 inch thick over hard rock.	Had to use extra surface area due to thickness of loose material. bottom had scattered alcyonarian population.

Table 3
Sand Sampling Field Notes - Transect #3

Station	Depth	Material Size Analysis in cm3 >½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
½	10'	--	--	3	3097	none	open sand	Approx. half way between Sta. 1 and beach
1	20'	5	11	90	2994	none	open sand	--------
2	16'	--	--	1	3099	none	open sand	--------
3	25'	--	--	8	3092	approx. 75% coverage	open sand	sand had "dusty" covering
4	30'	--	--	15	3085	" "	" "	sand had "dusty" covering
5	30'	--	2	43	3055	none	" "	worm tubes made of glued material were present

Table 3
Sand Sampling Field Notes - Transect #3 (continued)

Station	Depth	Material Size Analysis in cm3 >½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
6	36'	3	7	175	2915	none	open sand just west of rocky area	rocky area had heavy alcyonarian population
7	42'	--	1	40	3059	none	open sand approx. 50' east of rocky area "reef"	--------
8	47'	--	2	35	3063	none	open sand	sand had slight "dusty" covering
9	52'	1	1	20	3078	patches of *Caulerpa* and red filamentous algae approx. 8-10' across	open sand	sample taken in open sand - no algal covering

Table 3

Sand Sampling Field Notes - Transect #3 (continued)

Station	Depth	Material Size Analysis in cm3 >½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
10	58'	--	--	23	3077	patches of *Caulerpa* and red filamentous algae approx. 20-30' across	open sand	--------
11	60'	2	3	45	3050	algal mat	open sand approx. 150' west of rocky area	rocky area had heavy alcyonarian population
12	65'	30	4	115	2951	patches of *Caulerpa* approx. 20' across	open sand	sample taken in *Caulerpa* patch
13	62'	1	5	55	3039	algal mat and *Caulerpa* was present	open sand	sample taken in open sand

Table 3

Sand Sampling Field Notes - Transect #3 (continued)

Station	Depth	Material Size Analysis in cm3 >½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
14	55'	25	34	465	2576	none	on top of a reef	sample taken in sand patch 2' from anchor
15	50'	70	30	755	2245	none	on top of a reef	sample taken in sand patch about 20' north of anchor
16	65'	90	115	900	1995	-------------	on top of a reef	sample taken in sand patch about 20' south of anchor

Table 3
Sand Sampling Field Notes - Transect #3 (continued)

		Material Size Analysis in cm3						
Station	Depth	>½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
17	73'	330	155	360	2255	medium algal covering	reef area approx. 30' to the west very coarse sand	sample hard to take in the coarse sand
18	90'	310	140	360	2290	medium algal covering	flat bottom very coarse sand	--------
19	102'	220	160	350	2370	*Caulerpa* and *Halimeda* patches	same as above	scattered alcyonarian and sponge population
20	110'	125	135	420	2400	very light algae population	same as above	scattered alcyonarian population

Table 4
POMPANO BEACH OUTFALL REGION

Sand Analysis and Field Notes

Station	Depth	>½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
Outfall Periphery 11/11/69	90'	30	80	540	2450	None	Patch reef area	Sand was black, "greasy", and gave off H_2S odor. Citrus seeds, Al-foil, and one cigarette filter found in sample.
100' N 11/11/69	92'	100	50	180	2770	None	Patch reef area	Tan sand with few black particles, citrus seeds, and al-foil.
100' E 11/11/69	95'	6	17	160	2917	None	Patch reef area	Same as above
100' S 11/11/69	89'	4	14	200	2882	None	Patch reef area	Same as above

Table 4
POMPANO BEACH OUTFALL REGION (continued)

Sand Analysis and Field Notes

Station	Depth	>½"	½-¼"	¼-1/12"	<1/12"	Algal Covering	Geological Features	Comments
100' W 11/11/69	89'	30	40	260	2770	None	Patch reef area	Same as above
Outfall Periphery 1/14/70	90'	65	45	325	2665	None	Patch reef area	Sand was black, "greasy", and gave off H_2S odor. Citrus seeds, Al-foil and cigarette filters were found in sample.

Table 4
POMPANO BEACH OUTFALL REGION (continued)

Sand Analysis and Field Notes

Station	Depth	½"	½-¼"	¼-1/12"	1/12"	Algal Covering	Geological Features	Comments
Outfall 1/22/70	88'	5	30	865	2200	None	Sample taken in pile at end of pipe.	All material was black, gave off H_2S odor. Sample contained chicken bone, several small pieces of metal, and numerous citrus seeds.
50' N 1/22/70	91'	50	40	245	2765	None	Patch reef area	Sample contained pieces of black debris.

Table 4
POMPANO BEACH OUTFALL REGION (continued)

Sand Analysis and Field Notes

Station	Depth	½"	½-¼"	¼-1/12"	1/12"	Algal Covering	Geological Features	Comments
Outfall pile 2/16/70	88'	7	25	1220	1848	None	Sample taken in pile.	All materials black and sample contained Al-foil and numerous citrus seeds.

SAMPLE PROCESSING

All samples were processed within four to six hours after being taken. The material was sieved with ocean water, using 1/2", 1/4" and 1/12" sieves. The material retained by each sieve was examined, the specimens were removed and preserved in 70% alcohol.

IDENTIFICATION

Identification of specimens beyond the basic classification of phylum and class was difficult at times, due to the scarcity of biological keys for this area. Frequently, keys that are applicable are out of date or out of print.

The organisms were separated to species, and classification carried as far as possible. The polychaetes were the most numerous organisms. Mr. Jack Taylor, Aquatic Biologist with the U. S. Bureau of Commercial Fisheries, St. Petersburg Beach, Florida, classified them to the family level, and a few to species. This was rapidly accomplished on short notice. Time permitted only the separation and classification of the organisms of transect three at Boca Raton and the outfall region at Pompano Beach. The organisms of transects one and two at Boca Raton were classified only to phylum or class.

With the exception of the stations on transect one at Boca Raton, all samples were analyzed for particle size, see Tables 2, 3, and 4, and Figures 5, 6, 7 and 8. The amount of material (sand, shell fragments, coral debris, etc.) retained by each sieve was volumetrically determined by liquid displacement. This is not an accurate geological method and the results were meant only for comparison with the biological data.

RESULTS

The data obtained is presented in concise chart, table, or graph form in order to simplify analysis and present a compact report. The following terms are used in the field notes and graphs and require definition:

> Coarse rubble slope - The area lying seaward of the main reef and adjacent patch reefs. The bottom consists of large shell fragments, coral debris, sand, and sometimes Halimeda plates. The bottom has the appearance of being flat, but has a seaward decline.

Figure 5

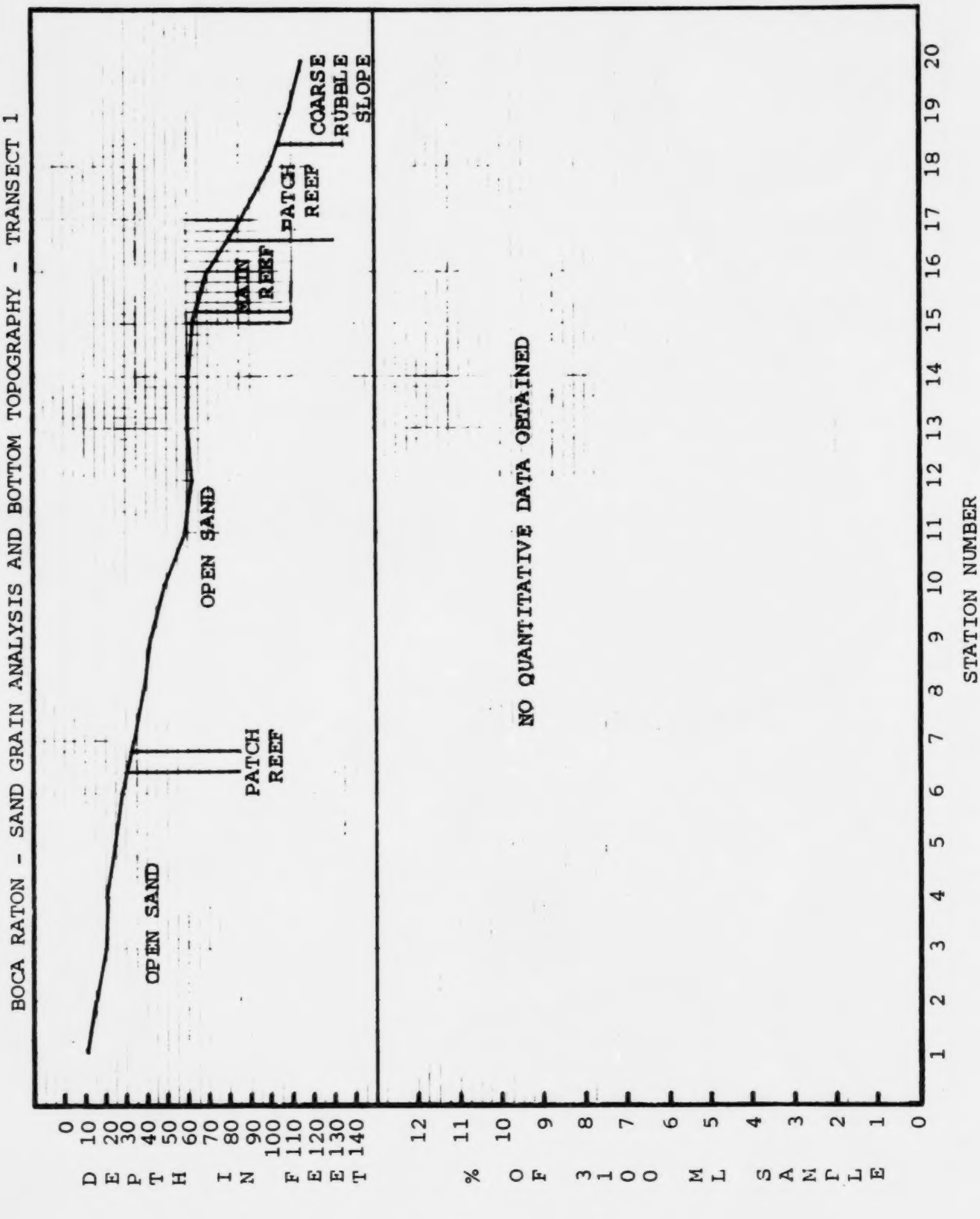

BOCA RATON - SAND GRAIN ANALYSIS AND BOTTOM TOPOGRAPHY - TRANSECT 1
DEPTH IN FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
OPEN SAND
PATCH REEF
OPEN SAND
MAIN REEF
PATCH REEF
COARSE RUBBLE SLOPE
% OF 3100 ML SAMPLE
12
11
10
9
8
7
6
5
4
3
2
1
0
NO QUANTITATIVE DATA OBTAINED
STATION NUMBER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Figure 6

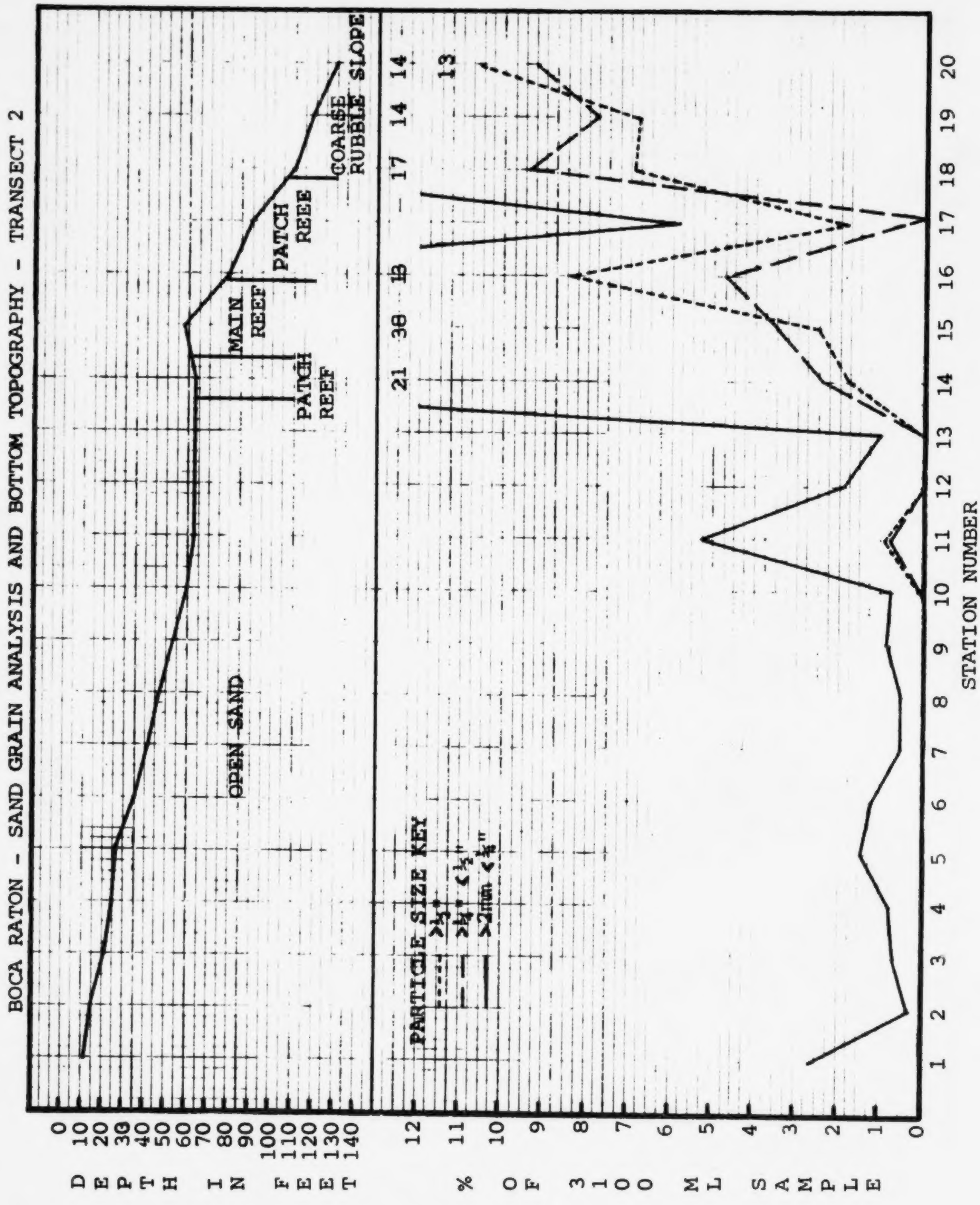

BOCA RATON - SAND GRAIN ANALYSIS AND BOTTOM TOPOGRAPHY - TRANSECT 2
DEPTH IN FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
OPEN SAND
PATCH REEF
MAIN REEF
PATCH REEF
COARSE RUBBLE SLOPE
% OF 300 ML SAMPLE
12
11
10
9
8
7
6
5
4
3
2
1
0
21
38
15
17
14
14
13
PARTICLE SIZE KEY
>½"
>¼" <½"
>2mm <¼"
STATION NUMBER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Figure 7

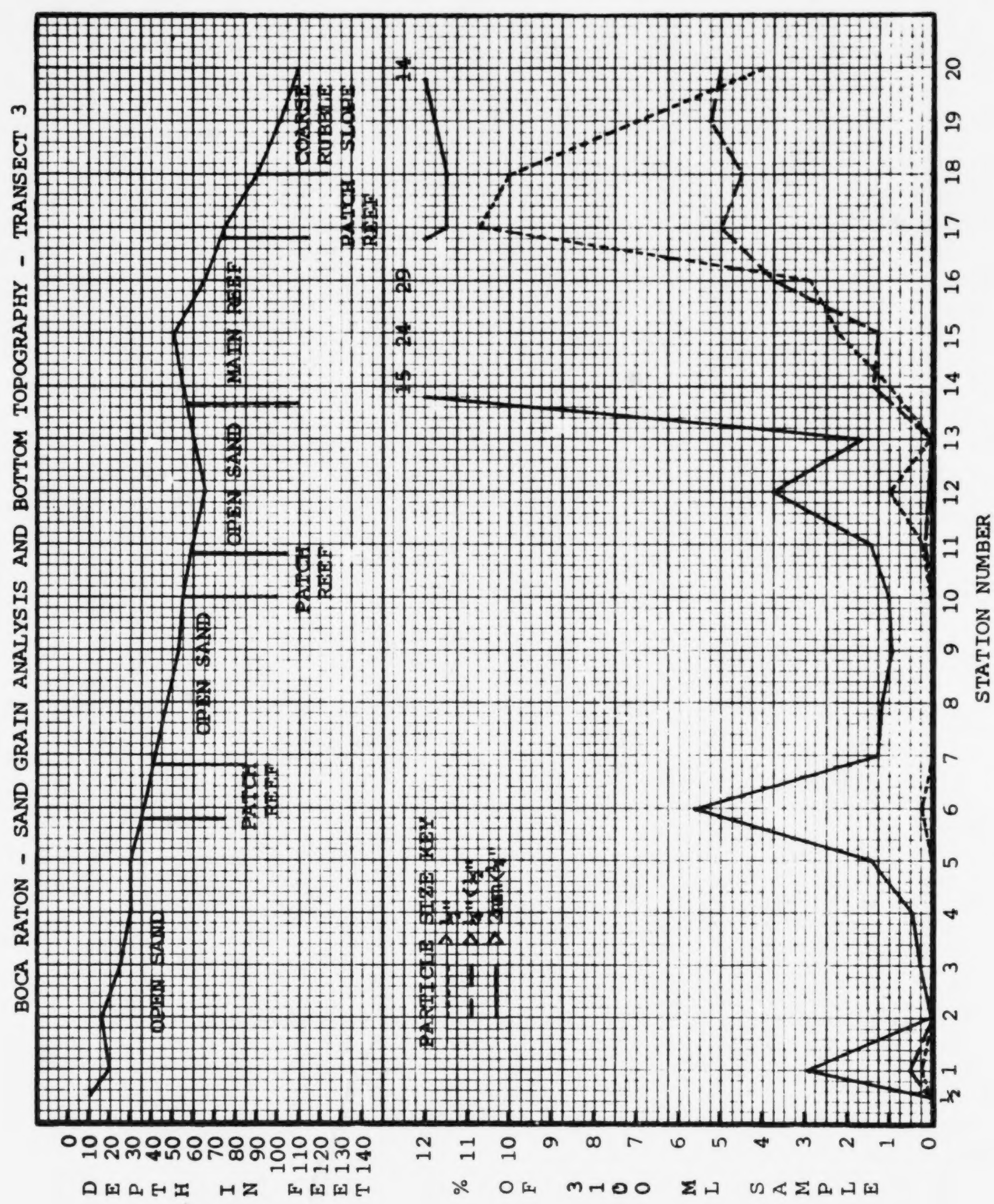
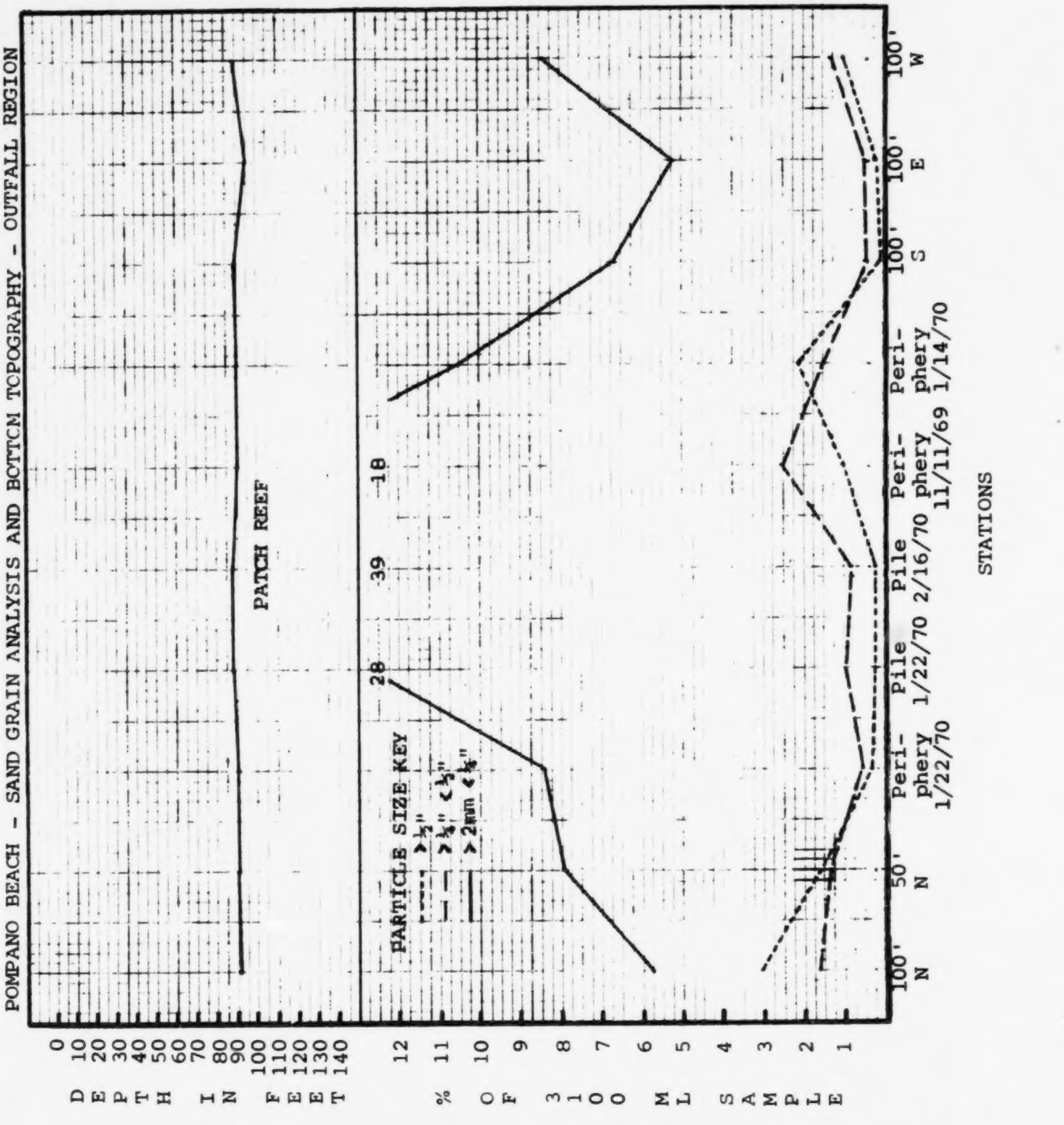

BOCA RATON - SAND GRAIN ANALYSIS AND BOTTOM TOPOGRAPHY - TRANSECT 3
DEPTH IN FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
% OF 300 ML SAMPLE
12
11
10
9
8
7
6
5
4
3
2
1
0
OPEN SAND
PATCH REEF
OPEN SAND
PATCH REEF
OPEN SAND
MAIN REEF
PATCH REEF
COARSE RUBBLE SLOPE
15
24
29
14
PARTICLE SIZE KEY
> ½"
> ¼" < ½"
> 2mm < ¼"
STATION NUMBER
½
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Figure 8


POMPANO BEACH - SAND GRAIN ANALYSIS AND BOTTOM TOPOGRAPHY - OUTFALL REGION
DEPTH IN FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
PATCH REEF
% OF 3100 ML SAMPLE
12
11
10
9
8
7
6
5
4
3
2
1
28
39
18
PARTICLE SIZE KEY
> ½"
> ¼" < ½"
> 2mm < ¼"
100' N
50' N
Peri- phery 1/22/70
Pile 1/22/70
Pile 2/16/70
Peri- phery 11/11/69
Peri- phery 1/14/70
100' S
100' E
100' W
STATIONS

"Dusty" - A fine covering lying in the troughs of the sand ripples.

Fine Sand - Sand with approximately 95% or greater of the sample material smaller than 1/12 (2mm).

Open Sand - An area where there is no geological features such as reef or rock in the immediate vicinity.

Patch reef - Small isolated reef.

The species lists and specimen indices by station for Boca Raton and Pompano Beach (Tables 5, 6, 7, and 8) are divided into major groups such as Polychaeta, Mollusca, Arthropoda, etc. The specimens are listed as follows:

Polychaeta

15 - Opheliidae - Armandia aqilis
Explanation: 15 specimens of Amandia aqilis from the family Opheliidae were found in the sample.

Polychaeta

1 - Capitellidae - sp A
Explanation: One unidentified specimen from the family Capitellidae was found and given a species title of A to differentiate between it and other unidentified species of that family.

Anthropoda

Amphipoda

1 - unidentified sp E
Explanation: One specimen of an unidentified Amphipod was found and given a species title of E to differentiate between it and other unidentified Amphipoda.

The graphs of specimen number and specie number for the Boca Raton transect and Pompano Beach outfall area (Figures 9, 10, 11, 12, 13, and 14) represent only the groups of organisms which are found frequently or in considerable numbers. Several small groups such as Echiurida and Sipunculida are not graphed individually, but are considered in the total tabulations.

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3

Station 1/2 - 10'* - This station was located approximately half way between station 1 and the beach, (see page for explanation).

Polychaeta
  15 Opheliidae - Armandia agilis

Mollusca
  Gastropoda
    53 - Veneridae - Tivela floridana
    1 - Olividae - Oliva sp

Station 1 - 20'* - 300' from shore

Arthropoda
  Amphipoda
    1 - unidentified sp E

Mollusca
  Gastropod
    1 - Olividae - Oliva sp

Station 2 - 16'* - 600' from shore

Polychaeta
  1 - Opheliidae sp A

Arthropoda
  Amphipoda
    2 - Haustoriidae sp A

Mollusca
  Gastropoda
    1 - Veneridae - Tivela floridana

Station 3 - 25'* - 900' from shore

Polychaeta
  1 - Opheliidae - Armandia agilis
  2 - Opheliidae - Ammotrypane aulogaster

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Arthropoda
  Amphipoda
    2 - Haustoriidae sp A
    2 - Unidentified sp A

Chordata
  subphyla Cephlachordata
    1 - Amphioxus

Station 4 - 30'* - 1200' from shore

Polychaeta
  1 - Opheliidae - Ammotrypane aulogaster

Arthropoda
  Amphipoda
    4 - Lysianassidae sp A

Station 5 - 30'* - 1500' from shore

Polychaeta
  1 - Capitellidae sp A
  1 - Opheliidae - Armandia agilis

Arthropoda
  Amphipoda
    2 - Lysianassidae sp A

Mollusca
  Pelecypoda
    1 - Cardiidae - Cardium sp A
    1 - Veneridae - Pitar fulminata

Station 6 - 36'* - 1600' from shore

Polychaeta
  1 - Opheliidae - Ammotrypane aulogaster
  1 - Opheliidae - Armandia agilis

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Arthropoda
  Amphipoda
    1 - Haustoriidae sp A

Mollusca
  Pelecypoda
    1 - Cardiidae - Cardium sp A
    1 - Cardiidae - Cardium sp B

Chordata
  Cephlachordata
    1 - Amphioxus

Station 7 - 42'* - 2100' from shore

Arthropoda
  Amphipoda
    1 - Lysianassidae sp A
    1 - Unidentified sp C

Decapoda
  1 - Unidentified crab sp A

Mollusca
  Pelecypoda
    2 - Cardiidae - Cardium sp A
    4 - Veneridae - Pitar fulminata

Nemertina
  1 - Unidentified sp A

Station 8 - 47'* - 2400' from shore - Laboratory accident - The lid was cracked and sample dried up, allowing only basic identification.

Polychaeta
  2 - Unidentified sp A

Arthropoda
  Amphipoda
    1 - Unidentified sp D

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Decapoda
  1 - Unidentified shrimp sp B (lab accident)

Chordata
  Cephlachordata
    1 - Amphioxus

Bryozoa
  5 - Unidentified sp A

Station 9 - 52'* - 2700' from shore

Polychaeta
  1 - Arabellidae sp A
  1 - Capitellidae sp A
  1 - Orbiniidae sp A
  3 - Sabellidae sp A
  2 - Sabellidae sp B
  1 - Spionidae sp A
  1 - Spionidae sp B
  5 - Terebellidae sp A
  1 - Unidentified sp B

Arthropoda
  Amphipoda
    2 - Ampeliscidae - Ampelisca spinipes
    1 - Lysianassidae sp A

Decapoda
  1 - Albuneidae - Albunea gibbsi

Mollusca
  Pelecypoda
    3 - Cardiidae - Cardium sp A

Bryozoa
  38 - Unidentified sp A
  62 - Unidentified sp B

Station 10 - 58'* - 3000' from shore

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Polychaeta
- 1 - Arabellidae sp A
- 1 - Lumbrineridae sp A
- 1 - Ophellidae - Ammotrypane aulogaster

Arthropoda
- Amphipoda
  - 2 - Ampeliscidae sp A
  - 2 - Ampeliscidae - Ampelisca spinipes
  - 2 - Lysianassidae sp A

Mollusca
- Gastropoda
  - 1 - Unidentified sp A

Pelecypoda
- 1 - Cardiidae - Cardium sp A
- 1 - Veneridae - Pitar fulminata

Chordata
- Cephlachordata
  - 2 - Amphioxus

Bryozoa
- 60 - Unidentified sp A
- 5 - Unidentified sp B

Station 11 - 75'* - 3300' from shore

Polychaeta
- 1 - Capitellidae sp B
- 1 - Lumbrineridae sp A
- 2 - Nereidae sp A
- 1 - Orbiniidae sp B
- 1 - Phyllodocidae - Phyllodoce catenula

Arthropoda
- Amphipoda
  - 2 - Ampeliscidae - Ampelisca spinipes
  - 2 - Ampeliscidae sp A

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Mollusca
  Pelecypoda
    5 - Cardiidae - Cardium sp A
    1 - Venerida - Tivela floridana

Bryozoa
  13 - Unidentified sp A
  36 - Unidentified sp B

Sipunculida
  1 - Unidentified sp A

Station 12 - 80'* - 3600' from shore

Polychaeta
  2 - Glyceridae - Glycera sp
  2 - Maldanidae - Clymenella zonalie

Arthropoda
  Amphipoda
    1 - Podoceriidae sp A
    1 - Unidentified sp F

Decepoda
  1 - Unidentified shrimp sp C

Mollusca
  Pelecypoda
    3 - Veneridae - Pitar fulminata
    1 - Veneridae - Dosina elegans

Bryozoa
  14 - Unidentified sp B

Station 13 - 77'* - 3900' from shore

Arthropoda
  Decapoda
    1 - Inachidae sp A

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Mollusca
  Pelecypoda
    1 - Cardiidae - _Cardium_ sp A
    1 - Lucinidae - _Lucina_ _leucocyma_
    1 - Lucinidae - _Phacoides_ _nassula_
    2 - Veneridae - _Dosina_ _elegans_

Echinodermata
  1 - Ophiuroidea sp A

Bryozoa
  1 - Unidentified sp A
  3 - Unidentified sp B

Station 14 - 70'* - 4200' from shore

Polychaeta
  1 - Capitellidae sp A
  1 - Lumbrineridae sp A
  1 - Sabellidae sp A
  1 - Sabellidae sp C

Station 15 - 65'* - 4500' from shore

Polychaeta
  1 - Polynoidae sp A
  2 - Sabellidae sp B
  1 - Unidentified sp C

Arthropoda
  Decapoda
    1 - Calappidae sp A
    1 - Unidentified shrimp sp D

Mollusca
  Pelecypoda
    1 - Tellinidae - _Tellina_ sp

Echinodermata
  1 - Ophiuroidea sp B

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Chordata
  Cephlachordata
    1 - *Amphioxus*

Station 16 - 80'* - 4800' from shore

Polychaeta
  1 - Capitellidae sp B
  1 - Lumbrineridae sp A
  1 - Onuphidae sp A

Arthropoda
  Amphipoda
    1 - Ampeliscidae - *Ampelisca spinipes*

Chordata
  Cephlachordata
    3 - *Amphioxus*

Bryozoa
  1 - Unidentified sp C

Station 17 - 98'* - 5100' from shore

Polychaeta
  1 - Glyceridae sp A
  2 - Lumbrineridae sp B
  2 - Maldanidae - *Clymenella zonalie*
  1 - Sabellidae sp D
  1 - Spionidae sp C

Arthropoda
  Amphipoda
    1 - Ampeliscidae - *Ampelisca spinipes*

Echinodermata
  Echinoidea
    1 - Clypeasteridae - *Clypeaster rosaceus*
  Ophiuroidea
    1 - Unidentified sp C

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Chordata
  Cephlachordata
    1 - *Amphioxus*

Bryozoa
  1 - Unidentified sp D

Decopoda
  1 - Unidentified shrimp sp E

Echinodermata
  Echinoidea
    1 - Clypeastridae - *Clypeaster rosaceus*
  Ophiuroidea
    1 - Unidentified sp D

Chordata
  Urochordata
    Ascidiacea
      1 - Unidentified sp A

Station 20 - 100'* - 6000' from shore

Polychaeta
  2 - Capitellidae sp A
  1 - Eunicidae - *Eunice rubra*
  1 - Lumbrineridae - sp A
  1 - Nereidae sp B
  1 - Sabellidae sp A
  1 - Sabellidae sp B
  1 - Syllidae - *Haplosyllis spongicola*
  1 - Syllidae sp A

Arthropoda
  Amphipoda
    4 - Ampeliscidae - *Ampelisca spinipes*
    5 - Ampeliscidae sp A
    5 - Podoceridae sp B
    1 - Unidentified sp C
    1 - Unidentified sp G

*Water depth

Table 5

BOCA RATON SAND ANALYSIS

Specimen Index by Station - Transect 3 (continued)

Decapoda
  1 - Unidentified shrimp sp F

Echinodermata
  Ophiuroidea
    1 - Unidentified sp E

Miscellaneous
  2 - Unidentified worm

*Water depth

Table 6

POMPANO BEACH OUTFALL REGION

Specimen Index by Station

100' north of outfall - 11/11/69 - 92' - The sample was taken in a patch reef area. The sand was tan and contained a few black particles which constitute the pile at the outfall.

Polychaeta
- 1 - Amphinomidae sp A
- 1 - Capitellidae sp A
- 2 - Capitellidae Notomastus sp*
- 1 - Cirratulidae sp B
- 2 - Onuphidae sp A*

Arthropoda
- Amphipoda
  - 1 - Ampeliscidae Ampelisca spinipes
  - 2 - Ampeliscidae sp A
  - 1 - Podoceridae sp A*
  - 3 - Unidentified sp A

Mollusca
- Pelecypoda
  - 1 - Solemyacidae - Solemya occidentalis

Echinodermata
- Ophiuroidea
  - 1 - Unidentified sp A
  - 1 - Unidentified sp B

50' north of outfall - 1/22/70 - 91' - The sample was taken in a patch reef area and the tan sand contained more of the black particles that constitute the outfall pile.

Polychaeta
- 3 - Amphinomidae sp B
- 2 - Arabellidae sp A*
- 1 - Dorvilleidae sp A
- 2 - Glyceridae sp A
- 6 - Onuphidae sp A*
- 1 - Sabellidae sp A*
- 4 - Spionidae sp A
- 2 - Syllidae Haplosyllis spongicola

*species was found also at Boca Raton

Table 6

POMPANO BEACH OUTFALL REGION

Specimen Index by Station (continued)

Arthropoda
  Amphipoda
    11 - Unidentified sp A
    1 - Unidentified sp B
    1 - Caprellidae sp A

Mollusca
  1 - Cardiidae Cardium sp

Chordata
  Cephlachordata
    2 - Amphioxus

Echinodermata
  1 - Holothuroidea sp A

Nemertina
  4 - Unidentified sp A
  2 - Unidentified sp B
  5 - Unidentified sp C

Sipunculida
  1 - Unidentified sp A

Bryozoa
  1 - Unidentified sp A

Outfall Periphery - 1/22/70 - 90' - The sample was taken just beyond the outfall pile and right in front of the pipe. The sand was dark gray and contained some black particles that constitute the outfall pile.

Polychaeta
  4 - Amphinomidae sp A
  1 - Amphinomidae sp C
  1 - Arabellidae sp A*
  1 - Cirratulidae sp A
  1 - Glyceridae sp B
  1 - Nereidae Neanthes spp
  17 - Spionidae sp A
  2 - Spionidae sp B

*species was also found at Boca Raton

Table 6

POMPANO BEACH OUTFALL REGION

Specimen Index by Station (continued)

Arthropoda
  Amphipoda
    15 - Unidentified sp A
     1 - Caprellidae sp A

Copepoda
  2 - Harpacticoida sp A

Malacostraca
  1 - Cumacea - Bodotriidae

Chordata
  Cephtochordata
    4 - _Amphioxus_

Nemertina
  6 - Unidentified sp A
  1 - Unidentified sp B
 12 - Unidentified sp C

Outfall Pile - 1/22/70 - 88' - The sample was taken in the pile built up at the end of the 30 inch effluent pipe, see figure 4. All material was black, greasy, and gave off a strong hydrogen sulfide odor. The sample contained one femoral chicken bone, several small pieces of metal, and numerous citrus seeds.

Polychaeta
 10 - Capitellidae _Capitella_ _capitata_
 22 - Nereidae _Neanthes_ _succinea_ and _N_. _arenaccodentata_ mixed

Arthropods
  1 - Nebaliacea

Outfall Pile - 2/16/70 - 88' - The sample was taken in the same location as in Outfall Pile - 1/22/70. The sample material was black, greasy, and gave off a hydrogen sulfide odor. It contained citrus seed and several pieces of aluminum foil.

*species was also found at Boca Raton

Table 6

POMPANO BEACH OUTFALL REGION

Specimen Index by Station (continued)

Polychaeta
  5 - Capitellidae Capitella capitata
  1 - Nereidae Neanthes spp. mixed

Arthropoda
  Copepoda
    1 - Harpacticoida sp B

Outfall periphery - 11/11/69 - 90' - The sample was taken in the sand at the edge of the pile. The sand's consistancy was somewhat black and greasy and gave off a hydrogen sulfide odor.

Polychaeta
  2 - Arabellidae sp B
  1 - Capitellidae Notomastus sp*
  1 - Capitellidae sp B
  1 - Sabellidae sp A*

Mollusca
  Gastropoda
    1 - Olividae Oliva sayana
    1 - Nassariidae Nassarius albus (ambiquus)

Chordata
  Cephlachordata
    1 - Amphoixus

Outfall Periphery - 1/14/70 - 90' - The sample was taken in the same location as the previous periphery samples. The sample characteristics were similar to those of other periphery samples.

Polychaeta

  1 - Ampharetidae sp A
  1 - Amphinomidae sp D
  1 - Arabellidae sp C*
  1 - Capitellidae Notomastus sp*
  1 - Lumbrineridae sp A*
  1 - Onuphidae sp B
  4 - Onuphidae sp A
  4 - Spionidae sp A

*species was also found at Boca Raton

Table 6

POMPANO BEACH OUTFALL REGION

Specimen Index by Station (continued)

Arthropoda
  Amphipoda
    2 - Aoridae sp A
    4 - Aoridae sp B
    3 - Unidentified sp C

Decapoda
  1 - Dromiidae sp A

Mollusca
  Gastropoda
    1 - Nassariidae Nassarius albus (ambiguus)

Chordata
  Cephlachordata
    1 - Amphioxus

Echinodermata
  1 - Echinoidea sp A

Sipunculida
  1 - Unidentified sp B

Chaetognatha

  1 - Unidentified sp A

Misc.
  4 - Unidentified worm

100' south of outfall - 11/11/69 - 89' - The sand sample taken in a patch reef area was tan and contained a few black particles of which the outfall pile is composed.

Polychaeta
  1 - Sigalionidae sp A
  1 - Spionidae sp A
  1 - Fragment

Mollusca
  Gastropoda
    1 - Nassariidae Nassarius albus (ambiguus)

*species was also found at Boca Raton

Table 6

POMPANO BEACH OUTFALL REGION

Specimen Index by Station (continued)

Sipunculida
  2 - Unidentified sp C

Bryozoa
  6 - Unidentified sp A*

100' east of outfall - 11/11/69 - 95' - The sand sample obtained in a patch reef area was composed of tan sand and a few black particles of which the outfall pile is composed.

Polychaeta
  1 - Sabellidae sp A*
  1 - Terebellidae sp A

Arthropoda
  Amphipoda
    1 - Aoridae sp A
    1 - Aoridae sp B

Mollusca
  Gastropoda
    1 - Nassariidae Nassarius albus (ambiguus)

Bryozoa
  1 - Unidentified sp A

100' west of outfall - 11/11/69 - 89' - The sand sample obtained in the patch reef area was tan and contained very few black particles that are found in the outfall pile.

Polychaeta
  1 - Arabellidae sp D
  1 - Ampharetidae sp A
  1 - Dorvilleidae sp B
  1 - Maldanidae sp A
  1 - Onuphidae sp A*
  1 - Spionidae sp A

*species was also found at Boca Raton

Table 6

POMPANO BEACH OUTFALL REGION

Specimen Index by Station (continued)

Arthropoda
  Amphipoda
    1 - Lysianassidae sp A
  Decapoda
    1 - Unidentified shrimp sp A

Mollusca
  Gastropoda
    1 - Strombidae Strombus gigus (juvenile)

Scaphopoda
  1 - Siphonodentalidae Cadulus quadridentatus
  1 - Detaliidae Dentalium eboreun

Chordata
  Cephlachordata
    3 - Amphioxus

Bryozoa
  1 - Unidentified sp A

*species was also found at Boca Raton

Table 7

BOCA RATON SAND SAMPLING

Species List

Polychaeta

Arabellidae
- *unidentified sp A
- *unidentified sp B

Eunicidae
- *Eunice rubra*

Lumbrineridae
- *unidentified sp A
- unidentified sp B

Nereidae
- *Nereis pelagica*
- unidentified sp A
- unidentified sp B

Ophelidae
- *Armandia agilis*
- *Ammotrypane aulogaster*

Phyllodocidae
- *Plyllodoce catenula*

Sabellidae
- unidentified sp A
- *unidentified sp B
- unidentified sp C
- unidentified sp D

Spionidae
- unidentified sp A
- unidentified sp B
- unidentified sp C

Terebellidae
- unidentified sp A

Capitellidae
- **Notomastus* sp
- unidentified sp A
- unidentified sp B

Gylceridae
- *Glycera* sp
- unidentified sp A

Maldanidae
- *Clymenella zonalie*

Onuphidae
- *unidentified sp A

Orbiniidae
- unidentified sp A
- unidentified sp B

Polynoidae
- unidentified sp A

Sigalionidae
- unidentified sp A

Syllidae
- **Haplosyllis spongicola*
- unidentified sp A

Unidentified Polychaeta
- species A - lab accident
- species B
- species C
- species D - fragment

*species was found in the Pompano Beach outfall region also

Table 7

BOCA RATON SAND SAMPLING

Species List (continued)

Arthropoda

Amphipoda

- Ampeliscidae
  - **Ampelisca spinipes*
  - *unidentified sp A
- Leucothoidae
  - *Leucothoe* sp
- Podoceridae
  - unidentified sp A
  - *unidentified sp B
- Haustoriidae
  - unidentified sp A
- Lysianassidae
  - *Tryphosella sarsi*
  - unidentified sp A
- Unidentified Amphipoda
  - unidentified sp A
  - unidentified sp C
  - unidentified sp D
  - unidentified sp E
  - unidentified sp F
  - unidentified sp G

Isopoda

- Unidentified sp A

Decapoda

- Albuneidae
  - *Albunea gibbessii*
- Calappidae
  - unidentified sp A
- Unidentified Decapoda
  - unidentified sp A
  - unidentified shrimp sp B - lab accident
  - unidentified shrimp sp C
  - unidentified shrimp sp D - fragment
  - unidentified shrimp sp E
  - unidentified shrimp sp F
- Inachidae
  - unidentified sp A
- Palaenmonidae
  - *Periclimenes longicaudatus*

*species was found in the Pompano Beach outfall region also

Table 7

BOCA RATON SAND SAMPLING

Species List (continued)

Mollusca

- Gastropoda
  - Olividae
    - *Oliva* sp
  - Nudibranchia
    - Elysiidae
      - unidentified sp A
- Pelecypoda
  - Cardiidae
    - *Cardium* sp A
    - *Cardium* sp B
- Tellinidae
  - *Tellina* sp
- Veneridae
  - *Dosina elegans*
  - *Pitar fulminata*
  - *Tivela floridana*
- Lucinidae
  - *Lucina leucocyma*
  - *Phacoides nassula*

Echinodermata

- Ophiuroidea
  - unidentified sp A
  - unidentified sp B
  - unidentified sp C
  - unidentified sp D
  - unidentified sp E
  - unidentified sp F
- Echinoidea
  - Clypeastridae
    - *Clypeaster rosaceus*

Chordata

- Cephlochordata
  - *Amphioxus* sp
- Urochordata
  - Ascidiacea
    - unidentified sp A

Bryozoa

- unidentified sp A
- unidentified sp C
- *unidentified sp B
- unidentified sp D

*species was found in the Pompano Beach outfall region also

Table 7

BOCA RATON SAND SAMPLING

Species List (continued)

Sipunculida

unidentified sp A	unidentified sp B

Miscellaneous

unidentified worm

*species was found in the Pompano Beach outfall region also

Table 8

POMPANO BEACH OUTFALL REGION

Species List

Polychaeta

Ampharetidae
  unidentified sp A

Arabellidae
  *unidentified sp A
  unidentified sp B
  *unidentified sp C
  unidentified sp D

Cirratulidae
  unidentified sp A
  unidentified sp B

Glyceridae
  unidentified sp A
  unidentified sp B

Maldanidae
  unidentified sp A

Onuphidae
  *unidentified sp A
  unidentified sp B

Sigalionidae
  unidentified sp A

Syllidae
  **Haplosyllis spongicola*

Amphinomidae
  unidentified sp A
  unidentified sp B
  unidentified sp C
  unidentified sp D

Capitellidae
  Capitella capitata
  **Notomastus* sp
  unidentified sp A
  unidentified sp B

Dorvilleidae
  unidentified sp A
  unidentified sp B

Lumbrineridae
  *unidentified sp A

Nereidae
  Neanthes succinea
  N. arenacodentata

Sabellidae
  *unidentified sp A

Spionidae
  unidentified sp A
  unidentified sp B
  unidentified sp C

Terebellidae
  unidentified sp A

*species was found in the Boca Raton region also

Table 8

POMPANO BEACH OUTFALL REGION

Species List (continued)

Arthropoda

- Amphipoda
  - Ampeliscidae
    - **Ampelisca spinipes*
    - *unidentified sp A
- Caprellidae
  - unidentified sp A
- Podoceridae
  - *unidentified sp A
- Decapoda
  - Dromiidae
    - unidentified sp A
- Cumacea
  - Bodotriidae
    - unidentified sp A
- Nebaliacea
  - unidentified sp A
- Copepoda
  - Harpacticoida
    - unidentified sp A
    - unidentified sp B
- Aoridae
  - unidentified sp A
  - unidentified sp B
- Lysianassidae
  - unidentified sp A
- Unidentified Amphipoda
  - unidentified sp A
  - unidentified sp B
  - unidentified sp C
- Unidentified Decapoda
  - unidentified shrimp sp A

Mollusca

- Gastropoda
  - Olividae
    - *Oliva sayana*
  - Strombidae
    - *Strombus gigus* (juvenile)
- Nassariidae
  - *Nassarius albus* (*ambiguus*)

*species was found in the Boca Raton region also

Table 8

POMPANO BEACH OUTFALL REGION

Species List (continued)

- Pelecypoda
  - Cardiidae
    - *Cardium* sp
  - Solemyacidae
    - *Solemya occidentalis*

- Scaphopoda
  - Siphonodentalidae
    - *Cadulus quadridentatus*
  - Detaliidae
    - *Dentalium eboreun*

Echinodermata

- Ophiuroidea
  - unidentified sp A
  - unidentified sp B
- Holothuroidea
  - unidentified sp A
- Echinoidea
  - unidentified sp A

Chordata

- Cephlachordata
  - *Amphioxus* sp

Nemertina

- unidentified sp A
- unidentified sp B
- unidentified sp C

Sipunculida

- unidentified sp A
- unidentified sp B
- unidentified sp C

Chaetognatha

- unidentified sp A

Bryozoa

- *unidentified sp A

Miscellaneous

- unidentified worm

*species was found in the Boca Raton region also

Figure 9

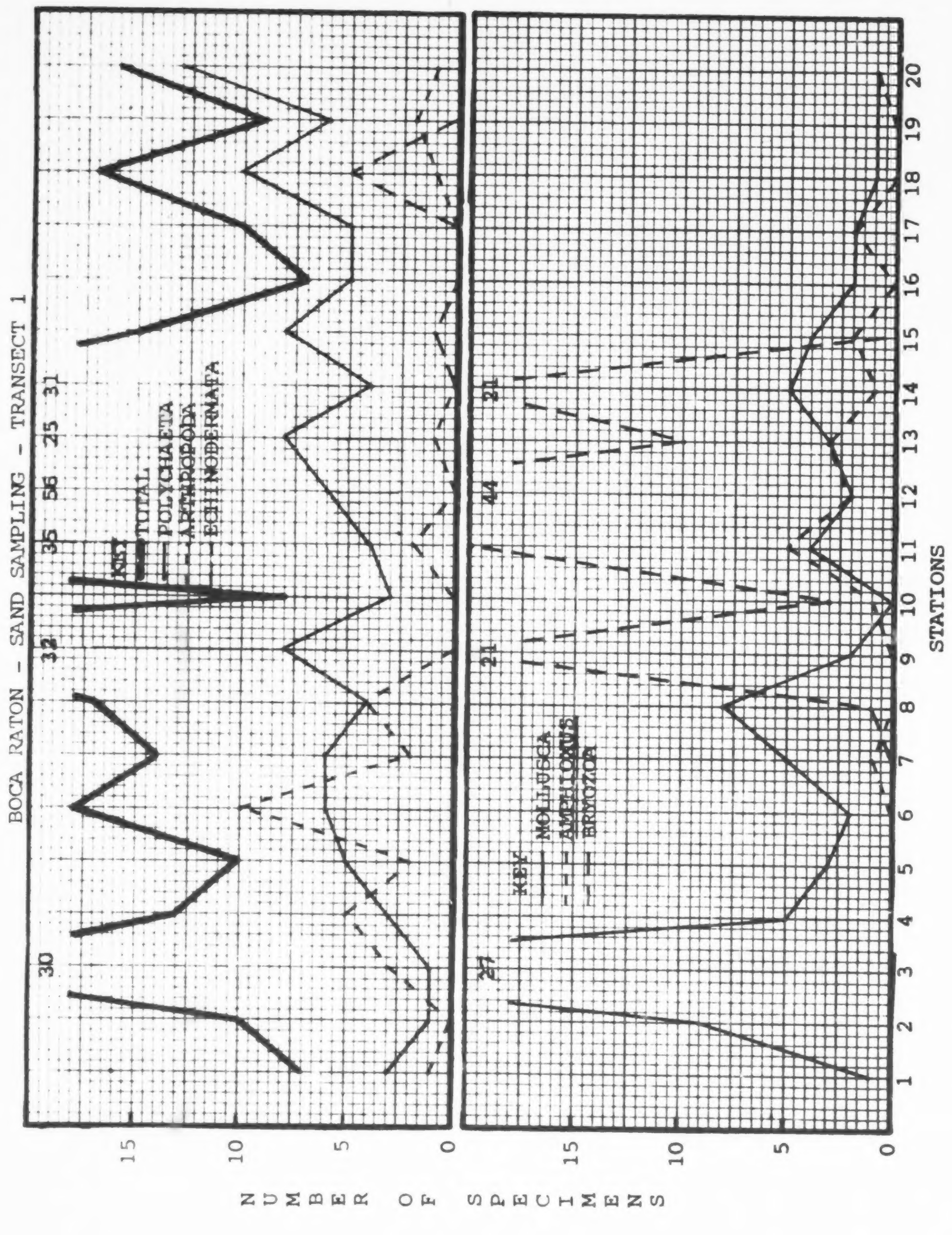

BOCA RATON - SAND SAMPLING - TRANSECT 1
KEY
TOTAL
POLYCHAETA
ARTHROPODA
ECHINODERMATA
KEY
MOLLUSCA
AMPHIOXUS
BRYOZOA
30
32
35
56
25
31
27
21
44
21
15
10
5
0
15
10
5
0
NUMBER OF SPECIMENS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
STATIONS

Figure 10

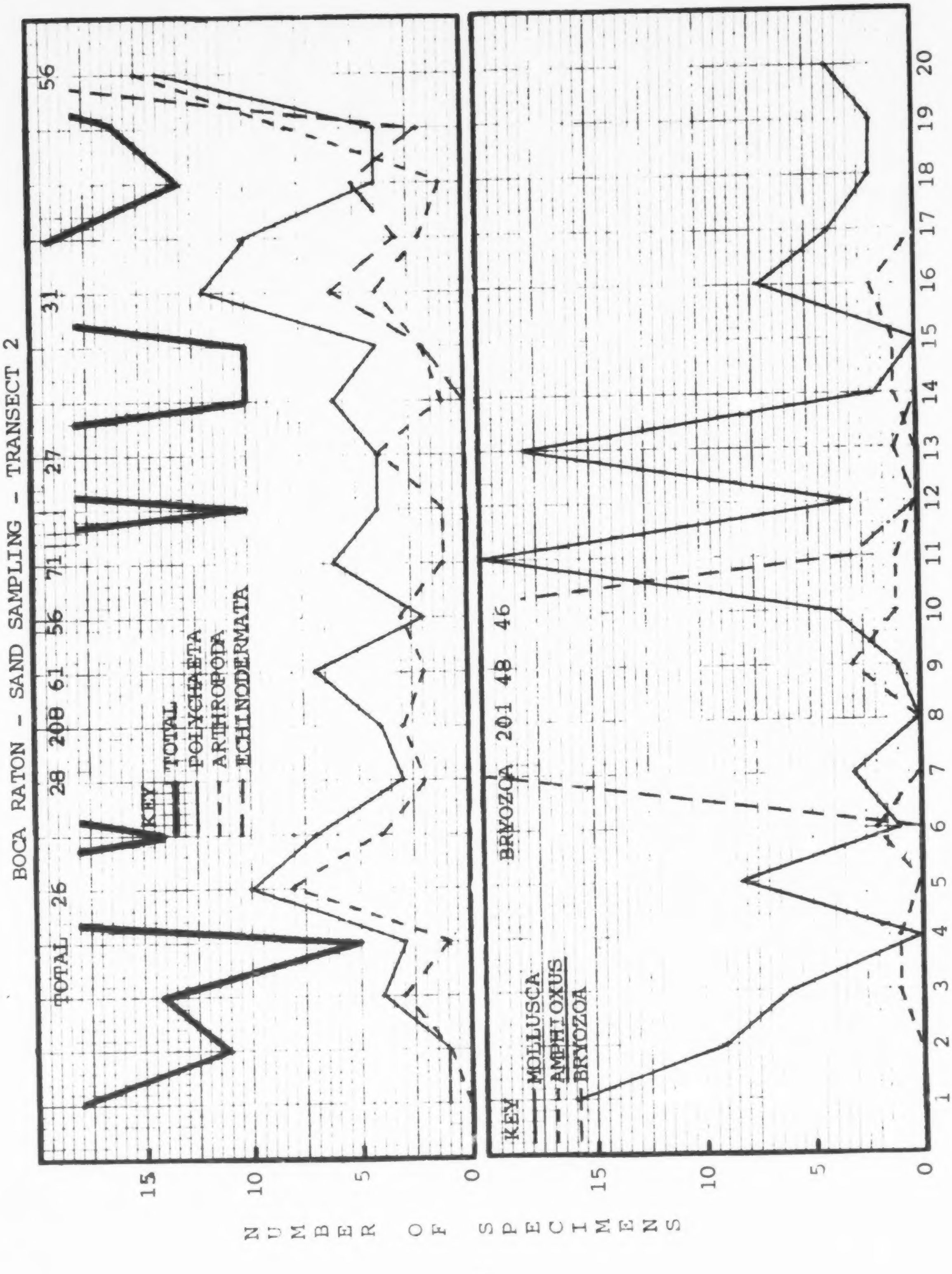

BOCA RATON - SAND SAMPLING - TRANSECT 2
TOTAL 26 28 208 61 56 71 27 31 56
KEY
TOTAL
POLYCHAETA
ARTHROPODA
ECHINODERMATA
BRYOZOA 201 48 46
KEY
MOLLUSCA
AMPHIOXUS
BRYOZOA
0
5
10
15
0
5
10
15
NUMBER OF SPECIMENS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
STATIONS

Figure 11

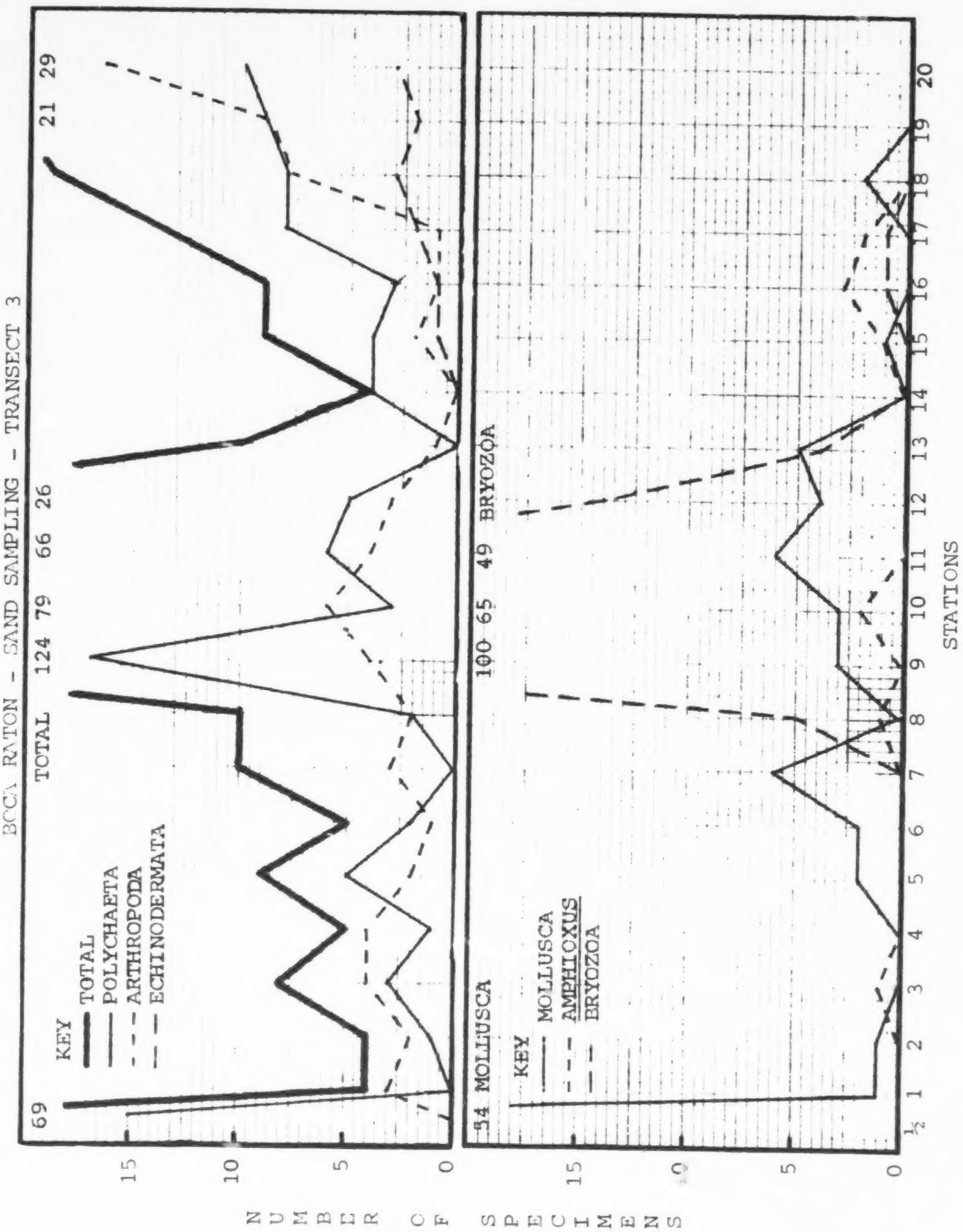

BOCA RATON - SAND SAMPLING - TRANSECT 3
TOTAL 124 79 66 26
69
21 29
KEY
TOTAL
POLYCHAETA
ARTHROPODA
ECHINODERMATA
54 MOLLUSCA
100 65 49 BRYOZOA
KEY
MOLLUSCA
AMPHIOXUS
BRYOZOA
15
10
5
0
15
10
5
0
½
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
STATIONS
NUMBER OF SPECIMENS

Figure 12

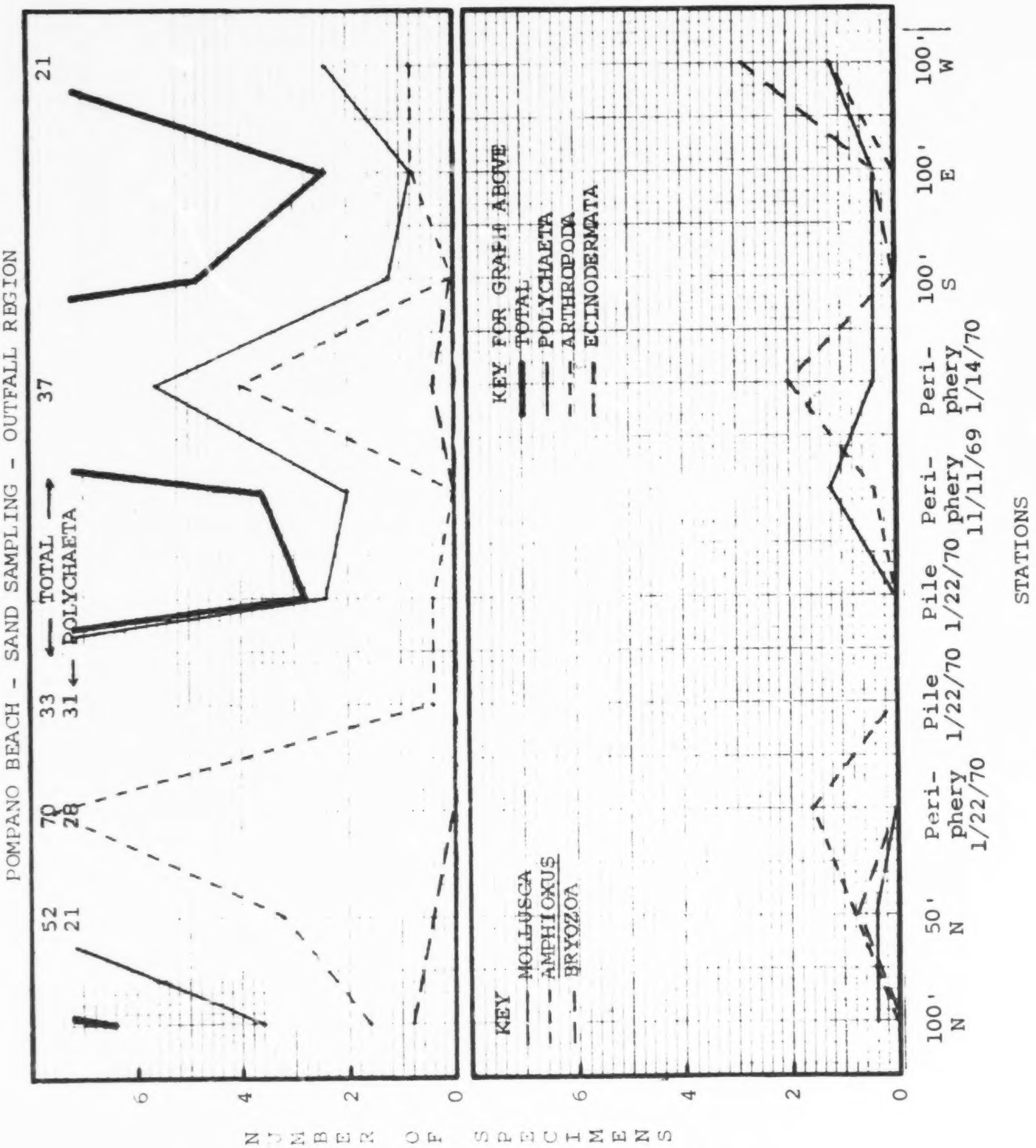

POMPANO BEACH - SAND SAMPLING - OUTFALL REGION
52
21
70
28
33
31
TOTAL
POLYCHAETA
37
21
KEY
MOLLUSCA
AMPHIOXUS
BRYOZOA
KEY FOR GRAPH ABOVE
TOTAL
POLYCHAETA
ARTHROPODA
ECINODERMATA
0
2
4
6
0
2
4
6
NUMBER OF SPECIMENS
100' N
50' N
Peri- phery 1/22/70
Pile 1/22/70
Pile 1/22/70
Peri- phery 11/11/69
Peri- phery 1/14/70
100' S
100' E
100' W
STATIONS

Figure 13

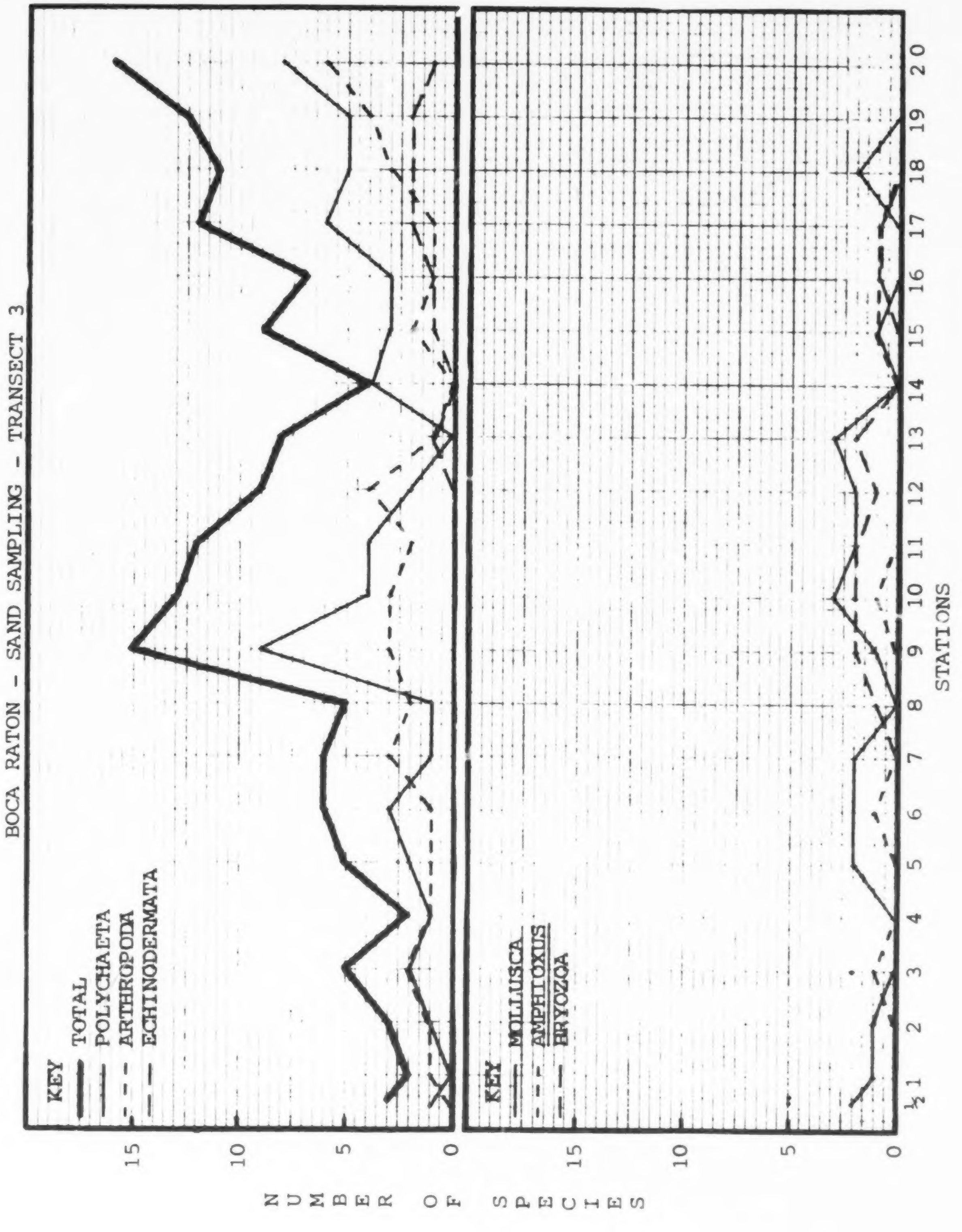
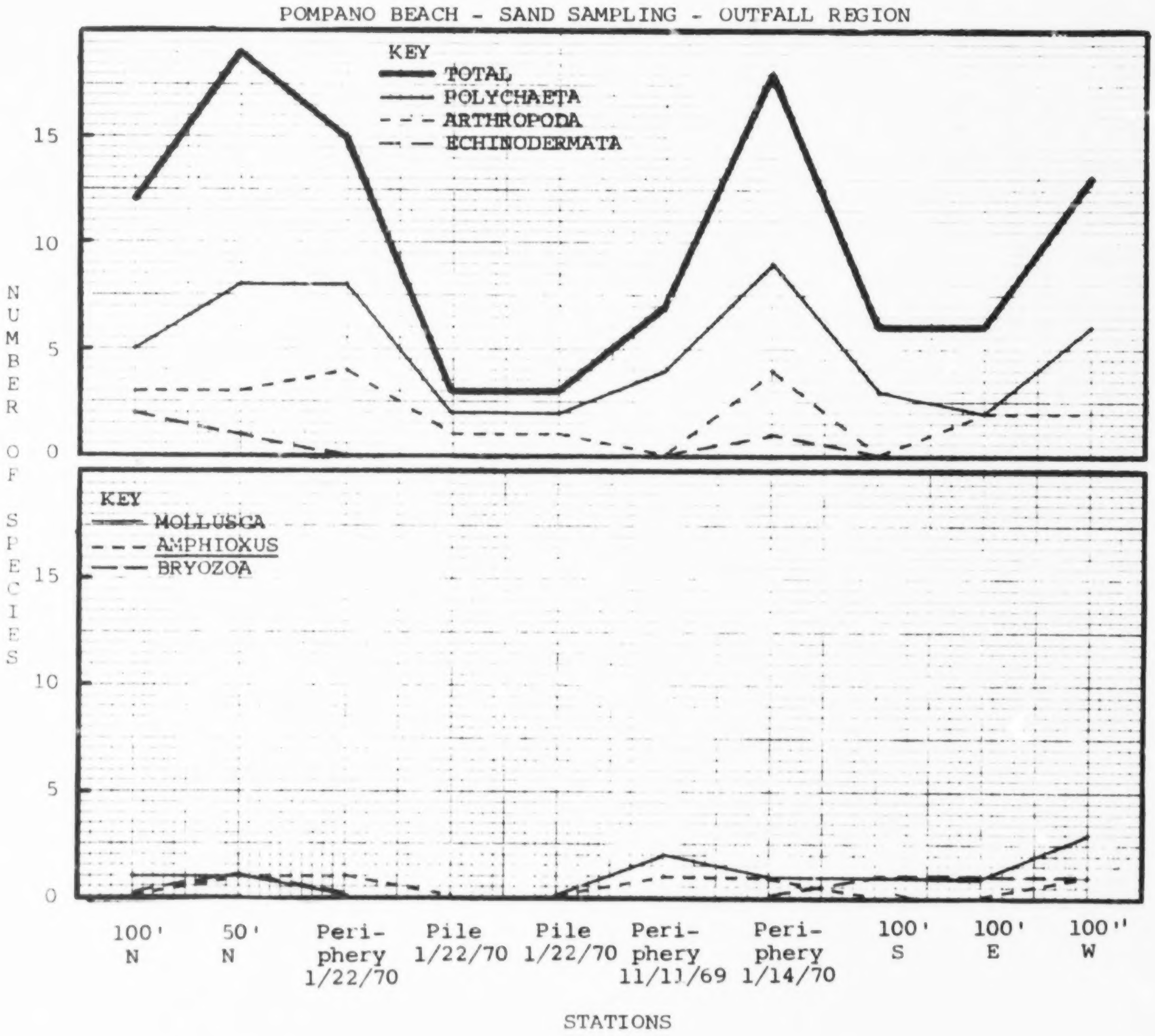

BOCA RATON - SAND SAMPLING - TRANSECT 3
KEY
TOTAL
POLYCHAETA
ARTHROPODA
ECHINODERMATA
KEY
MOLLUSCA
AMPHIOXUS
BRYOZOA
NUMBER OF SPECIES
15
10
5
0
15
10
5
0
STATIONS
½
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Figure 14


POMPANO BEACH - SAND SAMPLING - OUTFALL REGION
KEY
TOTAL
POLYCHAETA
ARTHROPODA
ECHINODERMATA
KEY
MOLLUSCA
AMPHIOXUS
BRYOZOA
NUMBER OF SPECIES
15
10
5
0
15
10
5
0
100' N
50' N
Peri-phery 1/22/70
Pile 1/22/70
Pile 1/22/70
Peri-phery 11/11/69
Peri-phery 1/14/70
100' S
100' E
100'' W
STATIONS

DISCUSSION

All samples were taken by the same person, employing identical sampling techniques. Coring devices were not feasible due to the frequency of coarse bottom material and the occasional thin layer of sand over hard rock. The scoop and container method permitted quantitatively equal samples to be obtained at each station. The similarity of the specimen graphs of transects 1, 2, and 3 at Boca Raton (Figures 9, 10, and 11) show a consistent correlation of the quantitative and qualitative data and substantiate the validity of the sampling technique.

A comparative transect was not completed at Pompano Beach, due to the time factor of processing and identification of specimens. Also, rough weather after October hindered diver sampling.

SPECIES DISTRIBUTION

There are numerous physical, chemical, and biological parameters governing the distribution of organisms. Some of the major ones are listed as follows:

Physical - temperature, turbidity, sedimentation, particulate matter, color, water depth, bottom composition and bottom stability.

Chemical - dissolved gases, dissolved nutrients, chlorinity, pesticides, heavy metals and oily substances.

Biological - propagation, proliferation, preditor-prey relationships, ecological chains and marine food webs.

The biological parameters are heavily dependent upon the chemical and physical parameters. Of the chemical and physical parameters listed, only water depth bottom composition and bottom stability vary sufficiently from station to station to influence species distribution and will be discussed with the individual groups.

The zonation of organisms was not discernible at Boca Raton until data analysis was completed. Zonation is clearly evident in one group, the bryozoans. Their zone is approximately 1500 feet wide and lies inshore of the main reef in water 40 to 65 feet deep.

This zone does not appear to correlate with substrate composition; however, it lies in the "shadow" of the reef and the water depth is such that the bottom would be disturbed only by severe storms and long swells.

Another discernible feature of the Boca Raton transects is a near shore zone of the mollusk *Tivella floridana*. They appear in varying distances from shore, from 150 feet* to 900 feet, and in depths from 10 to 20 feet. They are found on open, fine sand, but this is not a controlling factor in their distribution as they are not found in all areas of open, fine sand. There is insufficient correlation between water depth, distance from shore, bottom composition, and the *T. floridana* distribution to determine a cause and effect relationship regarding their distribution.

Substrate composition appears to be the factor determining the distribution of the echinoderms, especially the dominating Ophiuroidea (brittle stars). The adult organisms require a substrate which provides cover, protection and meets their biological requirements which are provided by the main reef and the coarse rubble slope lying seaward of it (see Figures 5, 6, and 7).

There are no evident zonation of the polychaete group as a whole, but there is a more subtle species zonation within the group (see Table 9). *Armandia agilis* was found in depths, ranging from 10 to 40 feet with the maximum number appearing approximately 150 feet from shore and in 10 feet of water. *Ammotrypane aulogaster* appeared to be widely distributed in a zone with water depth ranging from 16 to 58 feet. *A. agilis* and *A. Aulogaster* did not appear in depths greater than 36 and 58 feet respectively, thus exibiting limited zonation. *Eunice ruba* appeared to exhibit the most limited distribution of the polychaetes, as it was found only in depths greater than 90 feet for the stations covered and in the coarse rubble habitat. This data does not indicate whether bottom composition or water depth is the dominant parameter.

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*Station 1/2, transect 3, Boca Raton was established after collection data indicated mollusk zones in transects 1 and 2 which lie to the north and south of transect 3. A sampling station at 1/2 the distance from shore to station 1 or 150 feet from shore located these organisms.

Table 9
BOCA RATON - SPECIES DISTRIBUTION

Station	½	1	2	3	4	5	6	7	8	9	10
Depth	10	20	16	25	30	30	36	42	47	52	58
Polychaeta											
Armandia agilis	X			X		X	X				
Ammotrypane aulogaster			X	X	X		X				X
Capitellidae sp A						X				X	
Sabellidae sp A										X	
Sabellidae sp B										X	
Lumbrineridae sp A											X
Clymenella zonalie											
Eunice rubra											
Arthropoda											
Lysianassidae sp A				X		X		X		X	X
Ampelisca spinipes										X	X
Ampeliscidae sp A											X
Haustoriidae sp A			X	X			X				
Mollusca											
Tivela floridana	X		X								
Cardium sp A						X	X	X		X	X
Pitar fulminata						X		X			X
Chordata											
Amphioxus				X			X		X		X
Bryozoa											
unidentified sp A									X	X	X
unidentified sp B										X	X

Table 9
BOCA RATON - SPECIES DISTRIBUTION (continued)

Station	11	12	13	14	15	16	17	18	19	20
Depth	60	65	62	55	50	65	73	90	102	110
Polychaeta										
Armandia agilis										
Ammotrypane aulogaster										
Capitellidae sp A				X						X
Sabellidae sp A				X						X
Sabellidae sp B					X			X		X
Lumbrineridae sp A	X			X		X				X
Clymenella zonalie		X					X		X	
Eunice rubra								X	X	X
Arthropoda										
Lysianassidae sp A										
Ampelisca spinipes	X	X						X		X
Ampeliscidae sp A	X							X		X
Haustoriidae sp A										
Mollusca										
Tivela floridana	X									
Cardium sp A	X		X							
Pitar fulminata		X								
Chordata										
Amphioxus					X	X	X			
Bryozoa										
unidentified sp A	X		X							
unidentified sp B	X	X	X							

All remaining species of polychaetes show little definite zonation as does the previous mentioned species. However, they do show a preference for water deeper than 50 feet. This depth corresponds closely with the inshore boundary of the bryozoans.

It is more difficult to establish zonation within the arthropod group, but a similarity with the polychaetes is evident. The unidentified Haustoriidae is found in water less than 40 feet deep, and the members of the family Ampeliscidae, Ampelisca spinipes and an unidentified species, are found in water deeper than 50 feet, see Table 9. Again, the inshore depth limit of the species found in deeper water corresponds very closely with that of the bryozoan zone. The distribution of the unidentified species A of the family Lysianassidae overlaps the seaward portion of the inshore species distribution and the shoreward portion of one of the offshore species distribution, see Table 9.

The distributions of the mollusks Pitar fulminata and Cardium sp appear to correspond somewhat with that of the unidentified arthropod species A of the family Lysianassidae. The chordate Amphioxus apparently has a wide distribution, as it was found in depths from 20 to 120 feet at Boca Raton. The minor phyla appear to be sparsely scattered and display no explicit zonation.

POMPANO BEACH OUTFALL REGION ZONATION

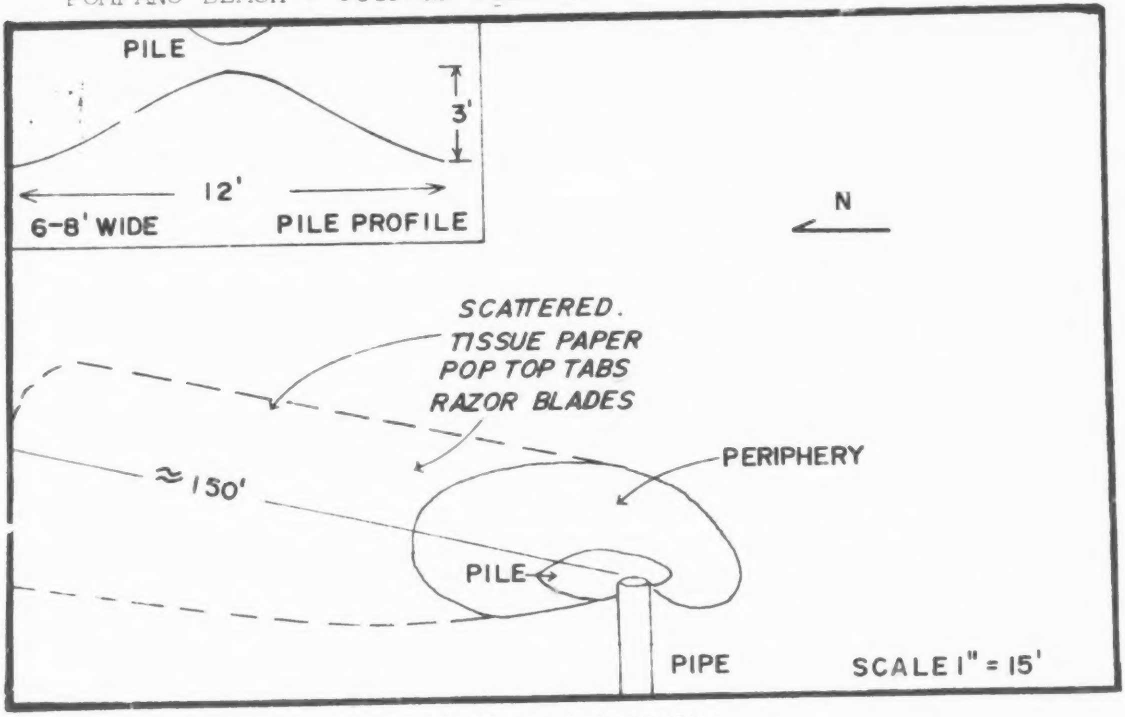
The zonation of the Pompano Beach outfall region is based upon samples taken in the immediate vicinity of the outfall discharge point. This encompasses samples taken up to 100 feet north, south, east and west of the discharge point.

The outfall pile is the product of the organically rich, dense effluent particles settling to the bottom at the end of the pipe, see Figure 4. Under "normal conditions" the pile is approximately 12 feet long on a north-south axis, 6 to 8 feet wide, and 3 feet high in the center, see Figure 15. The periphery is the result of the horizontal spread of this material to the surrounding area. The periphery, defined as the area where the sand is covered with black material, normally extends approximately 30 feet to the north, 20 feet to the south, 20 feet to the east, and 5 feet to the west. All measurements are given with the end of the outfall pipe as the reference point, see Figure 15.

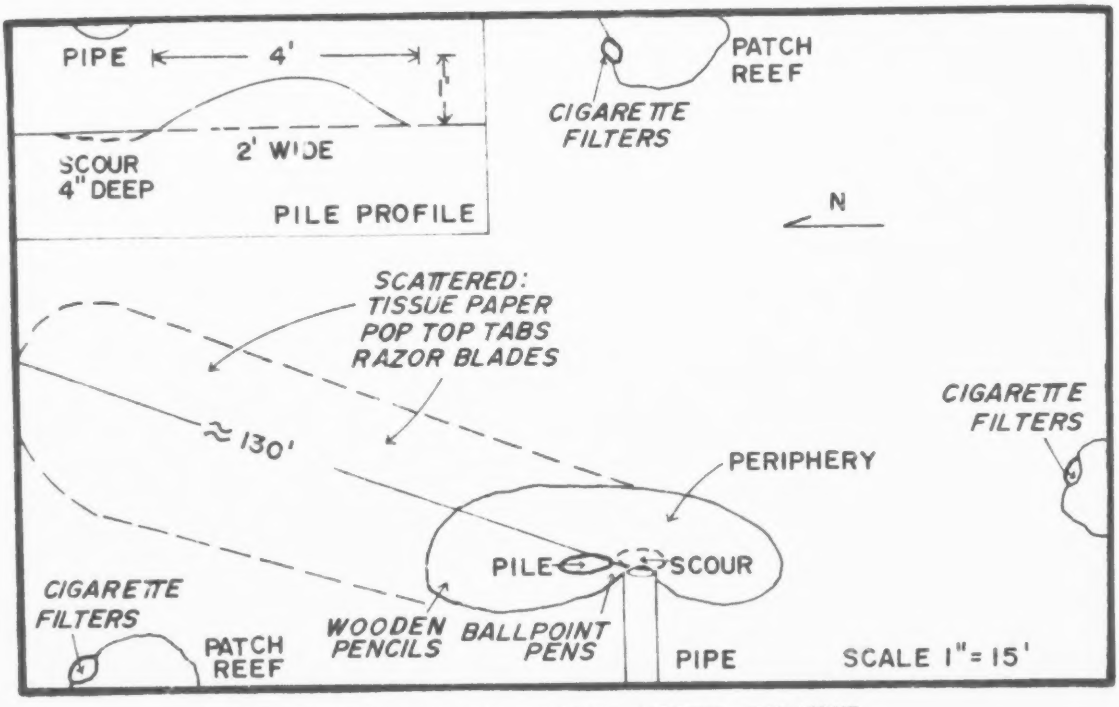
Outside the periphery lies an area extending mostly to the north where scattered debris can be found. The debris consists of numerous cigarette filters and small pieces of toilet tissue, moderate quantities of small pieces of metal (aluminum foil, "pop top" tabs, razor blades, etc.), and

Figure 15

POMPANO BEACH - OUTFALL PILE AND PERIPHERY FLUCTUATIONS


PILE
3'
12'
6-8' WIDE
PILE PROFILE
N
SCATTERED.
TISSUE PAPER
POP TOP TABS
RAZOR BLADES
PERIPHERY
≈150'
PILE
PIPE
SCALE 1" = 15'

"NORMAL" CONDITIONS


PIPE
4'
1'
SCOUR
4" DEEP
2' WIDE
PILE PROFILE
PATCH
REEF
CIGARETTE
FILTERS
N
SCATTERED:
TISSUE PAPER
POP TOP TABS
RAZOR BLADES
CIGARETTE
FILTERS
≈130'
PERIPHERY
PILE
SCOUR
CIGARETTE
FILTERS
WOODEN
PENCILS
BALLPOINT
PENS
PATCH
REEF
PIPE
SCALE 1" = 15'

FLUCTUATION DUE TO STRONG NORTH CURRENT

small quantities of wooden pencils, ball point pens, and black particles which compose the outfall pile and periphery. The majority of the effluent is less dense than the receiving body and, therefore, rises to the surface where it is at the mercy of the currents.

The pile and the periphery are in constant fluctuation due to the large variations of oceanographic features in the near shore waters.

An example of the fluctuations of the outfall pile and periphery is shown in Figure 15. The pile is located just north of the end of the pipe, and there is slight scouring where the pile is normally located. The outfall periphery has shifted somewhat to the north, and the bottom area that is littered with scattered debris extends to the northeast. Pockets of cigarette filters and tissue paper were found on the north side of patch reefs to the south, east and northwest of the outfall pipe; see Figure 15. This condition appears to be the result of a strong north current.

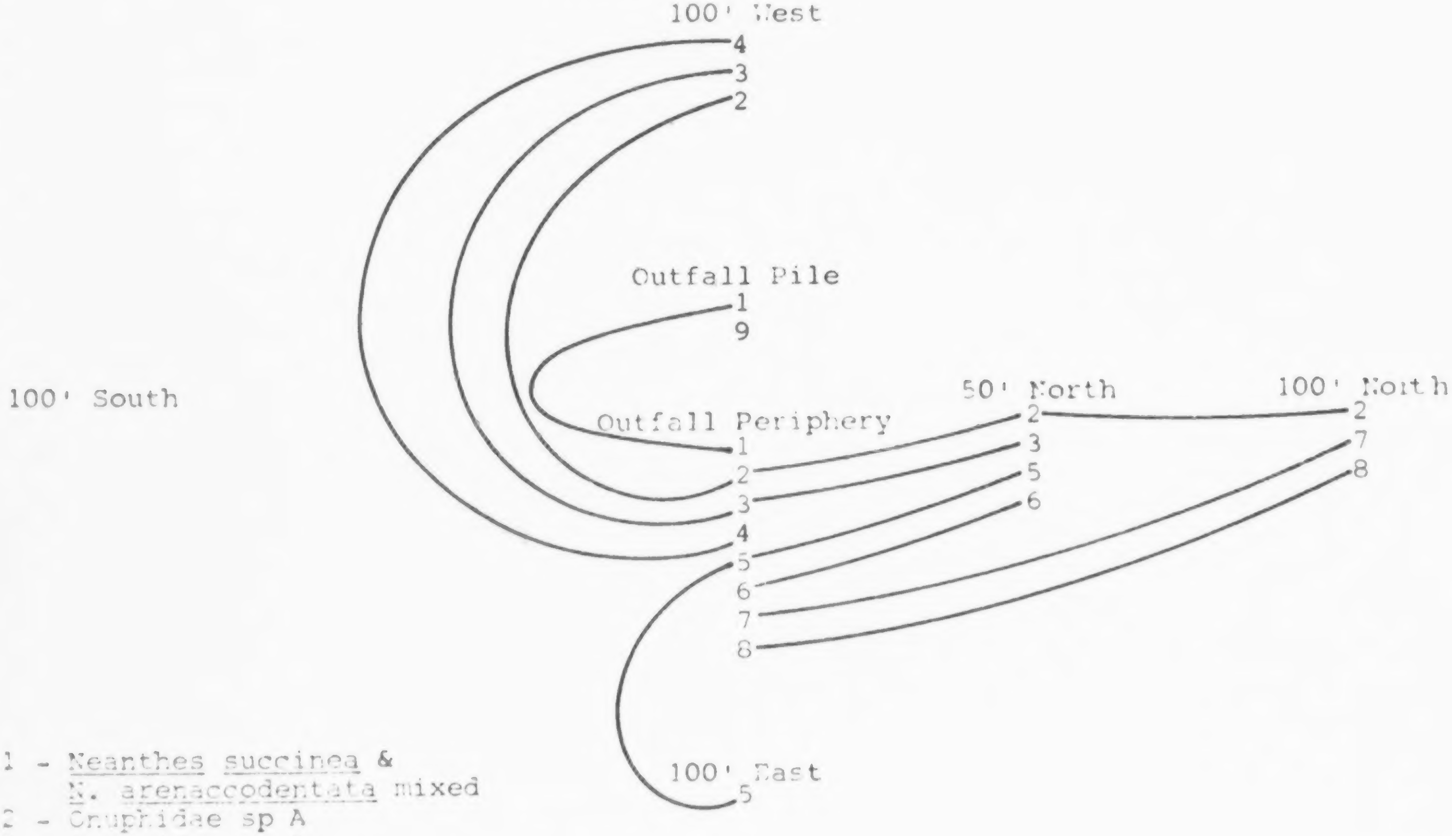
The polychaetes were the most numerous organisms in the outfall area and exhibit zonation in relation to the outfall; see Figure 16. There was repetition of eight species found in the outfall periphery and the stations located on the compass points. Seven species occur in the periphery and the stations to the north; see Figure 16. The periphery and the west sampling station had 3 species in common. There is little or no species correspondence between the periphery and the stations to the south and east. Neanthes succinea, N. arenaccodentata and Capitella were found exclusively in the organically rich outfall pile with the exception of one Neanthes specimen which was found in the outfall periphery, an area also organically rich. The distribution of the arthropods appear to be in a northerly and easterly direction from the outfall periphery, see Figure 17, with separate species recurring in each direction. The bryozoan colonies appear to encircle, but do not inhabit the outfall pile and periphery; see Figure 18. There was no species zonation within the echinoderm distribution.

Seven species of polychaetes were found at both Boca Raton and Pompano Beach in similar depths. A comparison of the number of specimens of these species showed no appreciable increase of specimens per sample at the outfall region over the Boca Raton area; see Figure 16.

There were no corresponding arthropod or mollusk species found at both the Boca Raton area and the Pompano Beach outfall region. Amphioxus was found at both locations, as was one unidentified bryozoan, species A at Pompano Beach which is species B at Boca Raton.

Figure 16

POMPANO BEACH OUTFALL REGION
POLYCHAETE DISTRIBUTION


100' West
4
3
2
Outfall Pile
1
9
100' South
Outfall Periphery
1
2
3
4
5
6
7
8
50' North
2
3
5
6
100' North
2
7
8
100' East
5

1 - *Neanthes succinea* &
N. arenaccodentata mixed
2 - Onuphidae sp A
3 - Spionidae sp A
4 - Ampharetidae sp A
5 - Sabellidae sp A
6 - Arabellidae sp A
7 - Amphinomidae sp A
8 - *Notomastus* sp
9 - *Capitella capitata*

Figure 17

POMPANO BEACH OUTFALL REGION
ARTHROPODA DISTRIBUTION

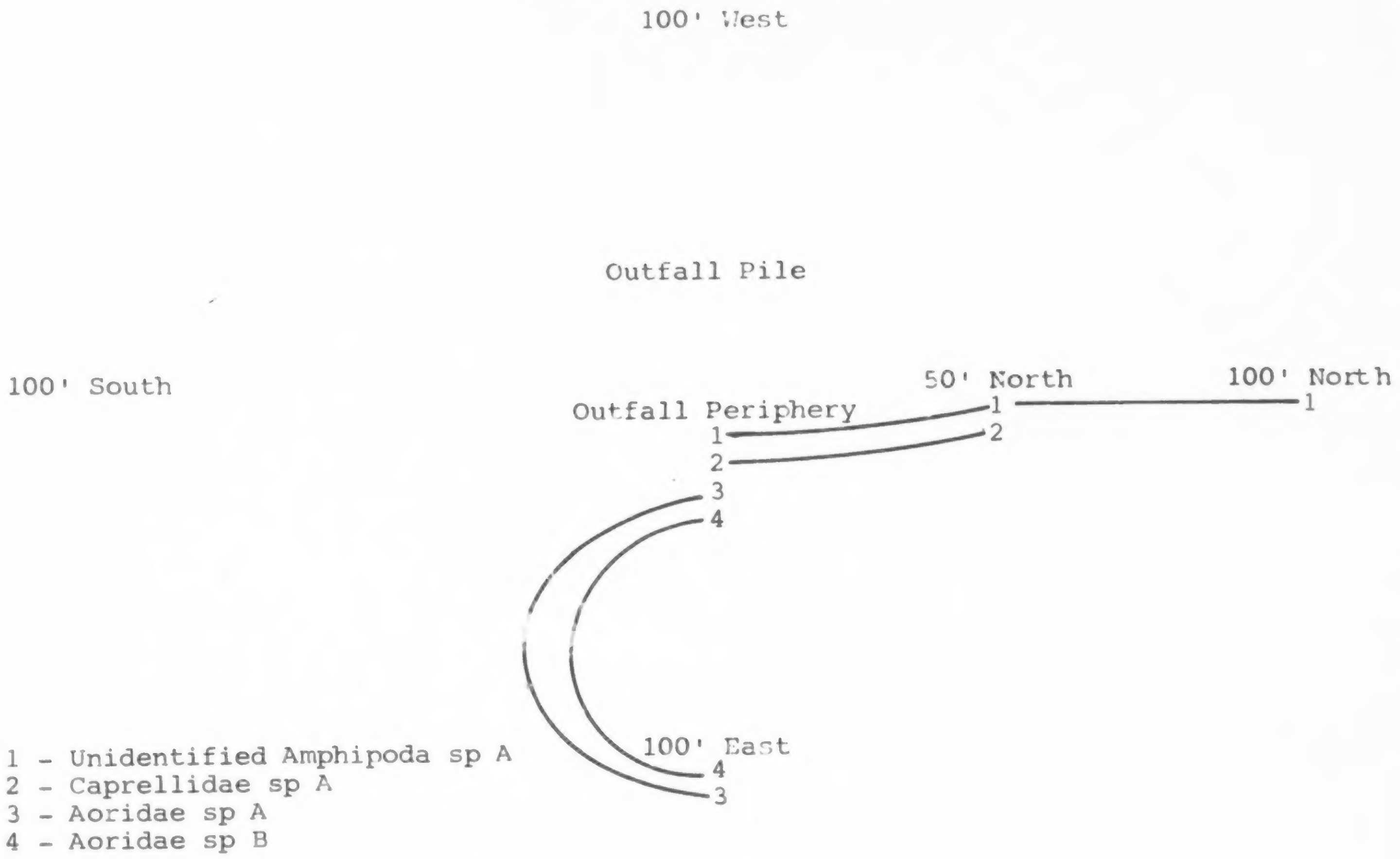
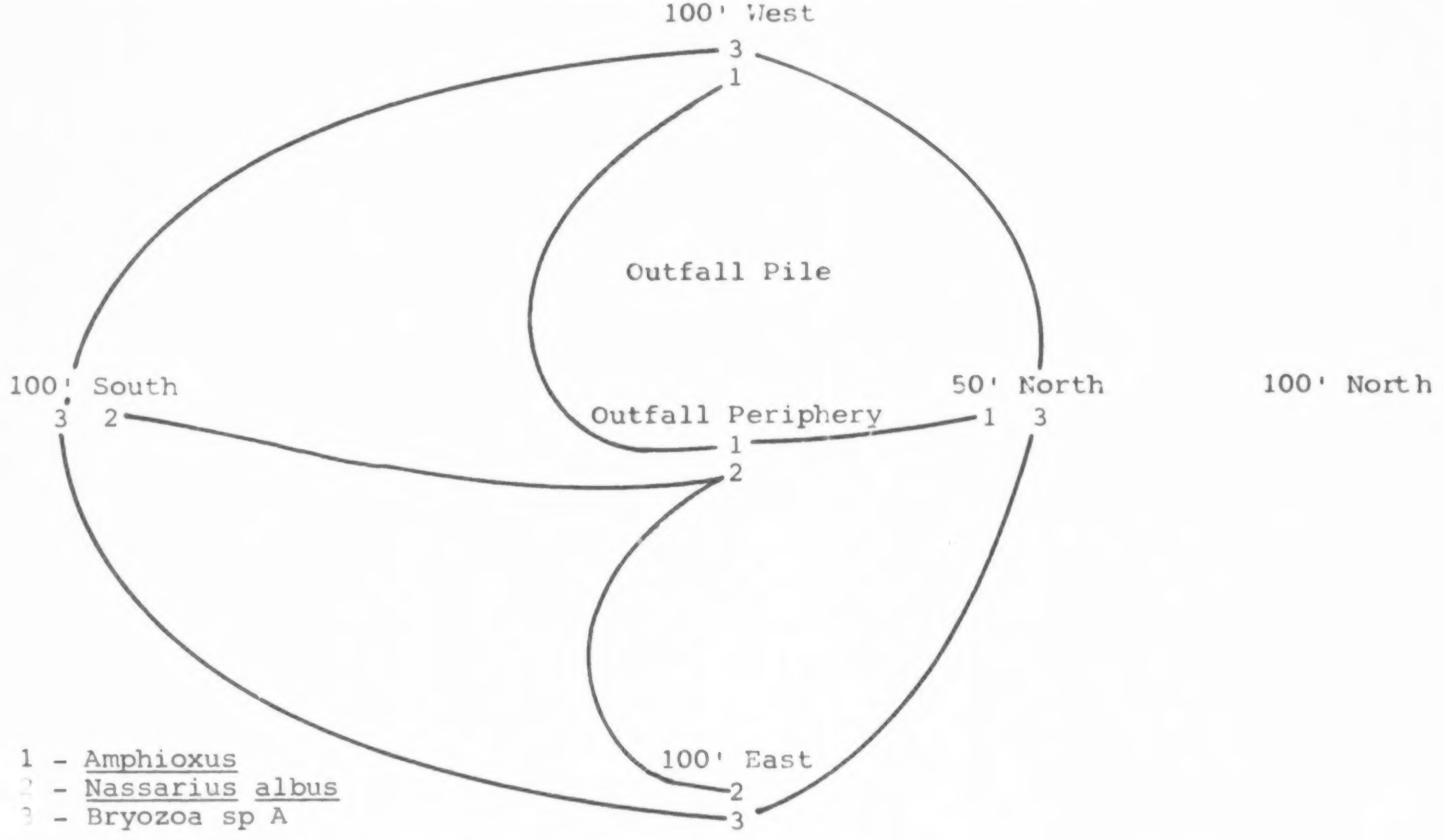

100' West
Outfall Pile
100' South
Outfall Periphery
50' North
100' North
100' East
1
2
3
4
1 - Unidentified Amphipoda sp A
2 - Caprellidae sp A
3 - Aoridae sp A
4 - Aoridae sp B

Figure 18

POMPANO BEACH OUTFALL REGION

AMPHIOXUS, MOLLUSK, AND BRYOZOA DISTRIBUTIONS


100' West
3
1
Outfall Pile
100' South
3
2
Outfall Periphery
1
2
50' North
1
3
100' North
100' East
2
3
1 - *Amphioxus*
2 - *Nassarius albus*
3 - Bryozoa sp A

The distribution of organisms in the immediate vicinity of the Pompano Beach outfall is primarily due to nutrients; oxygen levels; and hydrogen sulfide levels. The outfall pile has high concentrations of nutrients and hydrogen sulfide, but internally it is low in dissolved oxygen. Anerobic conditions evidently exist just beneath the surface (Lackey, 1969), but the surface is aerobic due to the constant flushing action of oxygen rich seawater. The periphery is organically rich sand, but does not have the same fauna as the pile due to the greater concentration of oxygen and a lower concentration of hydrogen sulfide. The above mentioned parameters in the area outside the periphery approach "normal" conditions. The levels of dissolved oxygen and hydrogen sulfide may be the major restricting parameters in species distributions in the outfall pile and periphery areas, but sufficient data was not available to support this hypothesis.

SPECIES DIVERSITY

Sepcies diversity has been utilized as a measurement regarding the "general health" of the environment. Favorable conditions are delineated by wide species diversity with few specimens of each species. Adverse conditions are accompanied by a decrease in the number of species and an increase in the number of specimens. Species diversity can be represented by the ratio of specimens per species, and, thus, is a number greater than one; the greater the number, the less diversity. Figures 11, 12, 13, and 14 indicate the number of specimens and species per station for transect three at Boca Raton and the Pompano Beach outfall region. Figures 19 and 20 show the specimen to species ratio per station of these two areas. Figure "19," the graph of Boca Raton area, delineates the "healthful" condition, and in general, has a low specimen to species ratio with two exceptions, Station 1/2 and the bryozoan zone. The specimen per species ratios serve as background information for comparison with the Pompano Beach data.

The specimen per species curve for the Pompano Beach outfall region, Figure 20, shows high ratios for the polychaetes at the outfall pile and the outfall periphery sample taken on 1/22/70. The anthropod ratios for the 50' north sample and the outfall periphery sample taken 1/22/70 are high, as are those for Amphioxus in the periphery samples taken on 1/14/70 and 1/22/70. The total ratio was high at the outfall pile and the outfall periphery sample on 1/22/70. Core samples indicated that the polychaete population which comprises nearly the entire biota was located at or near the surface of the outfall pile. The reason for the low specimen per species ratio of the pile sample taken on 2/16/70 is uncertain, but may be due to erosion of the

Figure 19

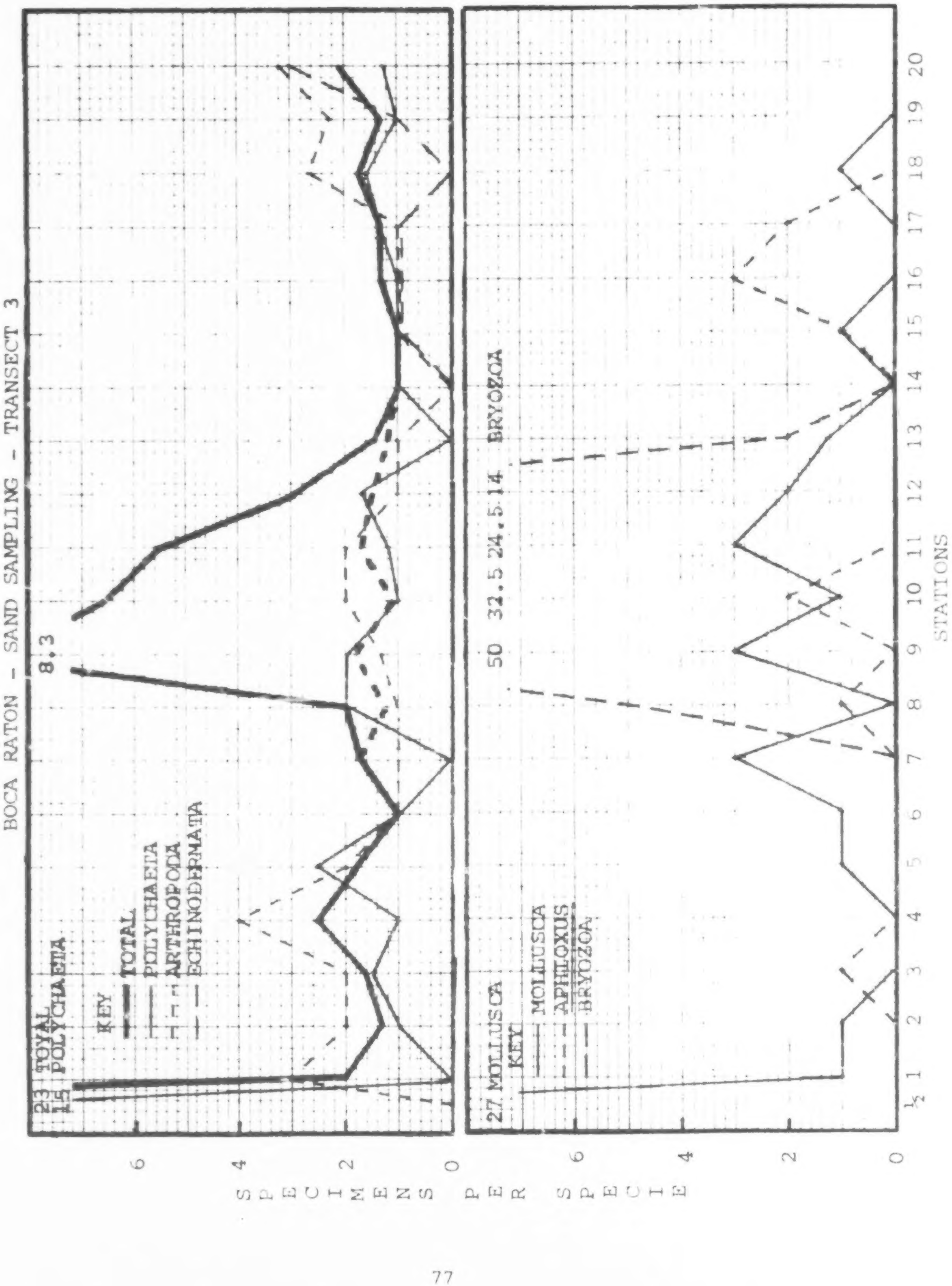
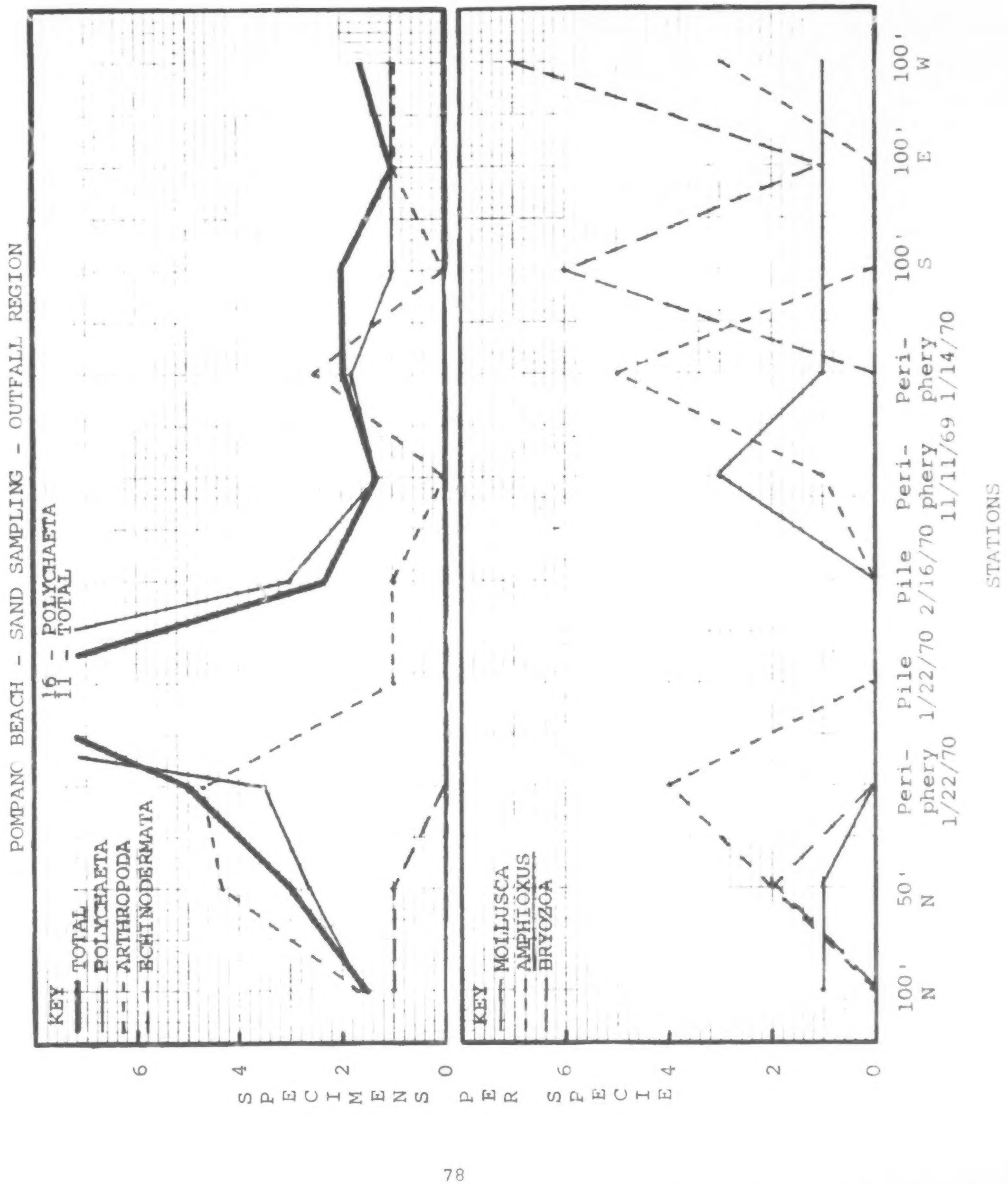

BOCA RATON - SAND SAMPLING - TRANSECT 3
23 TOTAL
15 POLYCHAETA
8.3
KEY
TOTAL
POLYCHAETA
ARTHROPODA
ECHINODERMATA
27 MOLLUSCA
KEY
MOLLUSCA
APHILOXUS
BRYOZOA
50 32.5 24.5 14 BRYOZOA
SPECIMENS PER SPECIE
0
2
4
6
½
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
STATIONS

Figure 20


POMPANO BEACH - SAND SAMPLING - OUTFALL REGION
KEY
TOTAL
POLYCHAETA
ARTHROPODA
ECHINODERMATA
16 - POLYCHAETA
11 - TOTAL
KEY
MOLLUSCA
AMPHIOXUS
BRYOZOA
6
4
2
0
6
4
2
0
SPECIMENS PER SPECIE
100' N
50' N
Peri- phery 1/22/70
Pile 1/22/70
Pile 2/16/70
Peri- phery 11/11/69
Peri- phery 1/14/70
100' S
100' E
100' W
STATIONS

pile surface during rough weather prior to sampling. The polychaete population did not have sufficient time to fully reestablish itself. Figure 19 shows that the polychaete specimen per species curve is very similar to that of the total. Thus, it can be further stated that the polychaetes "set the curve" in the Pompano Beach outfall region.

The outfall periphery is subject to variations in organic content, therefore, causing some fluctuation in the biota and accounting for the variability of the specimen content of the periphery samples. Due to the predominant north current, denser material in the effluent would tend to be deposited in this direction, and the organisms would establish themselves accordingly, thus accounting for the high specimen per species ratio of the "50 foot north" station.

STATISTICAL ANALYSIS

Figure 21 shows the mean specimen per species values for the stations in the Pompano Beach outfall region and the Stations 17, 18 and 19 on transect three at Boca Raton which are in depths similar to those at Pompano. The outfall region graph is a combination of north-south and east-west curves. The mean values for Stations 17, 18 and 19 are given as background information.

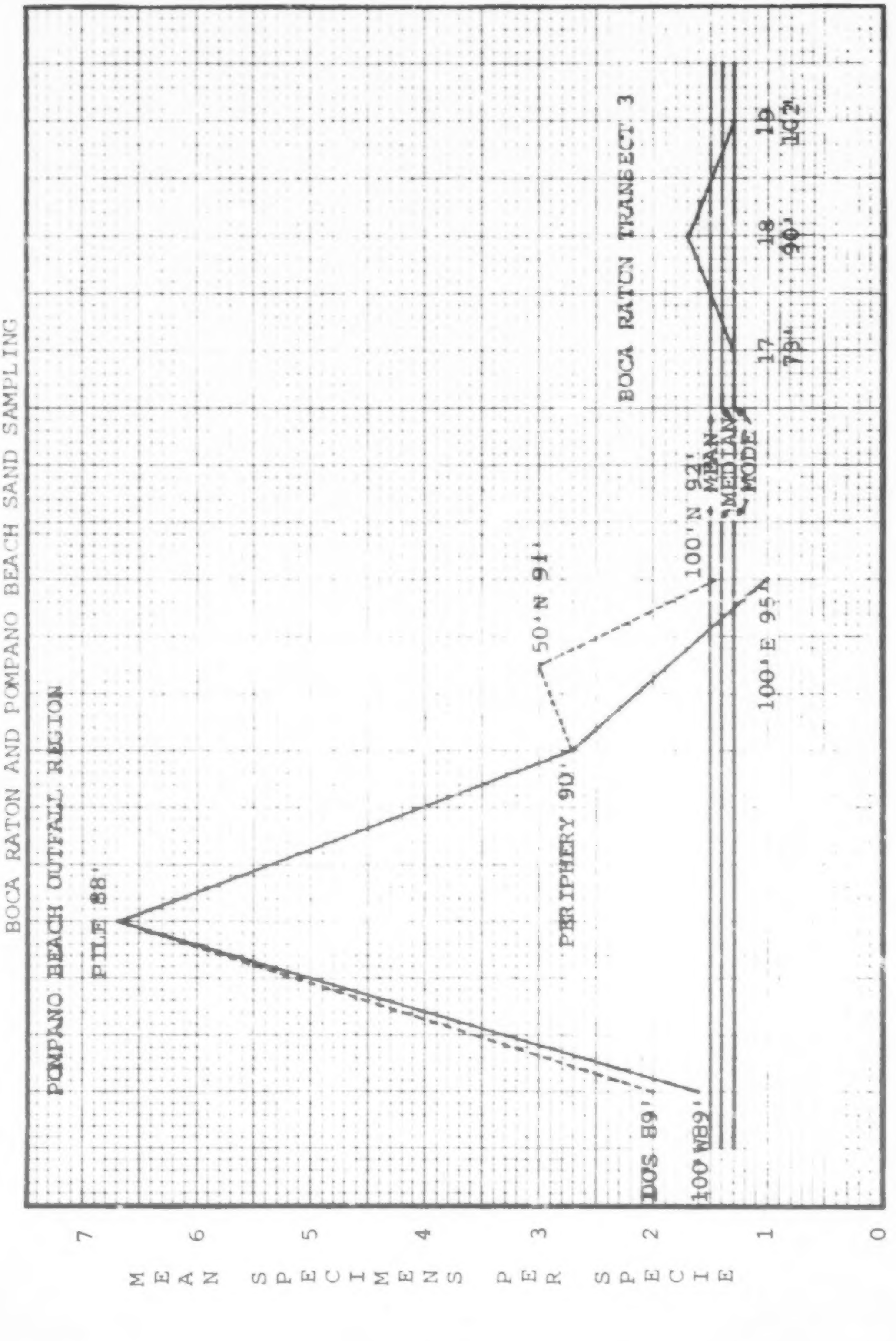
The ratios for the stations 100 feet from the outfall are very close to the Boca Raton background value, while the outfall pile mean ratio is 4.4 times the mean for Boca Raton. The outfall periphery mean ratio is almost twice the background value, as is the ratio for the station 50 feet to the north.

SUMMARY AND CONCLUSIONS

It is difficult to make firm conclusions concerning the distribution and relationships of the macroscopic benthic community to the Pompano and Delray outfalls, without having data previous to the outfall useage. Biological communities undergo continuous change on a variety of time scales in accordance to a large number of fluctuating environmental parameters. However, by comparing the areas in the vicinity of the outfalls to an area most likely removed from the influence, one can make suggestions as to the effect of effluent on the surrounding benthic communities.

The zonation and species diversity of the organisms at Boca Raton are due primarily to bottom stability.

Figure 21


BOCA RATON AND POMPANO BEACH SAND SAMPLING
POMPANO BEACH OUTFALL REGION
PILE 88'
PERIPHERY 90'
50'N 91'
100'N 92'
100'E 95'
100'S 89'
100'W89'
MEAN
MEDIAN
MODE
BOCA RATON TRANSECT 3
17
79'
18
90'
19
102'
7
6
5
4
3
2
1
0
MEAN SPECIMENS PER SPECIE

The stability is caused by the main reef which runs north and south in approximately 60 feet of water. The reef acts as an "underwater breakwater" in diminishing the turbulent effect of storm waves on the bottom sediment. The reef forms a sand "bowl" which lies inshore of the reef. It serves as a natural sediment trap and as a source of nutrients which are by-products of decaying organisms and the feces of living organisms. The relative quiescence of the sediment-water interface in the "bowl" helps retain the nutrients and offers a near shore habitat less subject to the rapid changes occuring in the shelf waters. Bottom stability is further supported by the presence of algae, Caulerpa and the red filamentous algae which forms a mat in the open sand, thus, indicating enrichment of the area. The advent of algae in the "bowl"; see Tables 1, 2, and 3, provides the necessary parameters such as harborage, food source, etc., which, in turn, produce species diversity. The zone of stable bottom begins in approximately 50 feet of water and extends almost to the inshore side of the main reef.

Inshore of the stable zone lies an area of relatively unstable bottom, due to wave action, and has very little or no algal covering. This area is inhabited by relatively few species as compared to the more stable zone. The sand samples taken in pockets on the reef were low in production of organisms in comparison with the surrounding areas. The coarse rubble slope area is high in benthic biota productivity due to bottom composition and stability.

The biological data from the Pompano Beach outfall region was compared with background data established at Boca Raton. This data indicates there are three zones in Pompano Beach outfall region: 1) unaffected; 2) tolerant or intermediate and 3) polluted zone.

The data from the stations 100 feet from the outfall compares closely with the background data from Boca Raton, thus indicating very little or no organic enrichment (the unaffected zone).

The lack of data prior to the operation of the Pompano outfall makes it impossible to state whether there has been an exclusion of organisms that inhabited the outfall region prior to activation. This can only be determined by a before and after study.

Surrounding the outfall pile is a zone defined as the outfall periphery. It is an area of esthetic pollution as it has a thin layer of black particles, citrus seeds, small pieces of metal, cigarette filters, small pieces of paper, etc., covering the sand. This area is inhabited by species tolerant to organic enrichment. Some of these organisms have been found at surrounding stations and on transect three at Boca Raton. This zone's exact extent is not known, however, the station 50 feet to the north shows close species correlation with the periphery. With more adequate sampling of the periphery, it would be possible to establish its extent and compile a more complete index of "tolerant organisms" in this area.

The data indicates that gross pollution exists only in the outfall pile. Visual observations lead us to believe that organic buildup is restricted to the pile and periphery due to the less dense effluent material rising to the surface and traveling horizontally with the current away from the point of discharge. The findings indicate that Neanthes succinea, N. arenaccodentata, Capitella capitata are indicators of pollution, as they were found exclusively in the outfall pile with one minor exception. According to Wass, from Olson & Burgess, 1967, N. succinea and C. capitata have been cited by numerous authors as indicators of organic pollution.

It is known that the pile and periphery fluctuate. Is there a seasonal fluctuation in the size of the outfall pile and periphery? Are the pile and periphery increasing in dimension? And if so, what is their effect on the fauna and flora of the area? Has there been an exclusion of organisms? There are still many unanswered questions. A thorough survey of the Pompano Beach area and an "after survey" of the Boca Raton area would permit a more vivid picture of sewage effluent effects on the macroscopic, benthic biota of the open ocean, continental shelf.

SECTION V

MICROBIOTIC ECOLOGY OF OCEAN SEWAGE OUTFALLS IN THE HOLLYWOOD-POMPANO BEACH-DELRAY BEACH AREA

ASPECTS OF THE PROBLEM

Outfalls for treated and untreated sewage in ocean water have produced much discussion pro and con as to whether this is a desirable method of waste disposal. Generally, if the sewage components do not come back to the beaches, little public interest is aroused until some magazine or newspaper prints a lurid account of the frightful consequences. Since such writings rarely, if ever, consider the alternatives, and since they are frequently based on inadequate knowledge of what actually occurs, much concern may be aroused.

In truth the problem has been too little studied up to the present. A seaside city or community, faced with rapid population growth and the necessity of sewage disposal can find very little information on whether or not it can utilize the ocean, how far out its outfall must extend, whether or not the sewage should first be treated, what can be incorporated in its sewage, and the biological effects of ocean disposal. This last problem has been studied during the past two years, and since microscopic algae and protozoa are probably most quickly responsive to environmental change, work has been concentrated on them.

At Pompano Beach engineering studies indicated an outfall about 6000 feet out, and at a depth of 90 feet on the continental shelf, would not "wash back" onto the beaches. Work has concentrated on this outfall, but studies of the Delray Beach, and Hollywood Beach outfalls, and other localities, especially some studies at places far removed from sewage, were done.

Because a first effect of sewage is to fertilize the receiving water, the first discernable biologic effect would be an increase in the biota of the water so fertilized. This is not simple to look for unless the amount of dilution is taken into account, and knowledge of the currents enables tracking of the enriched water. The following lines of work were carried out:

1. Quantitative and qualitative analyses of surface plankton from the shore to well into the Gulf Stream at intervals of about 1000 yards. This was principally at Pompano Beach.

2. Comparison with shelf plankton at various

other places. No data included.

3. Studies of the sediment-water interface microbiota beneath the Pompano Beach and Delray Beach outfalls, and for comparison, interface samples distant from outfalls.

4. Studies of organisms accumulating on slides in the vicinity of outfalls, and also at a distance from outfalls, as on the Boca Raton current meter.

5. Studies of the relation of organic matter and nutrients in cores from beneath the outfalls and elsewhere to the organisms present there.

6. A listing of the observed microorganisms in the area, with an evaluation of commonness or rarity, and seasonal occurrence.

7. Notes on macroscopic organisms beneath the outfalls.

RESULTS AND DISCUSSION

SURFACE TRANSECTS, SHORE TO GULF STREAM

Generally speaking, there is a decrease in the numbers per milliliter of microscopic algae and protozoa from shore to Gulf Stream with a sharp decrease in the Stream. These are all surface figures except for a few tows with a Clarke-Bumpus plankton net, No. 20. Some tows were made at 30 feet, 100 feet and 200 feet. Numbers were rather similar to a depth of 30 feet with sharp decreases at 100 and 200 feet. While this is probably a light effect, it should be noted that photosynthetic organisms, especially diatoms and dinoflagellates, were abundant and normally present in interface material as deep as 150 feet.

These surface samples were brought in unkilled but were protected from sunshine. Temperatures were disregarded since there is rather a small difference in winter and summer. In the laboratory the samples were centrifuged for 3 to 5 minutes at about 2200 rpm in conical-ended 50 ml tubes, the supernatant was decanted by pipetting and the catch reduced to 6, 12, or 25 drops, i.e., 6 drops equal 100 ml, or 1 drop equals 16-2/3 mls. A drop was put beneath a 25 mm square No. 1 cover glas and 2 paths across the cover, at right angles to each other, were counted at 100 and 400 diameters. One drop was generally good for only about 15 to 20 minutes due to lethal osmotic changes as the water evaporated around the edges. Counting and identification was by bright field illumination only, using a Leitz Labolux microscope.

Table 10 includes a list of the species found in these transects. It also indicates whether or not the organisms are common; that is, it gives frequency of occurence in the number of times these transects were analyzed. Table 10 is not quantitative, but it does indicate frequency of occurence in a 100 ml sample, which is the minimal amount of water examined by the water bottle-centrifuge method. Any set of transect samples shows the number of each species for one milliliter of raw water. Although such factors as plankton patchiness, direction of both wind and tidal current, salinity, etc., may interfere, the general pattern is a decrease from the shore seaward, with the numbers usually below 200 per ml at the inshore stations and decreasing to about 50 or 60 per ml at the Gulf Stream stations.

The most important fact is that numbers were consistently low, and with a midpoint about the station nearest where the boil from the outfall emerged. Blooms (500 or more organisms per ml) were rare. On a few occasions, a species would reach or exceed 500 per ml. For example August 5, 1968, one or possibly two species of a very small centric diatom (Cyclotella and/or Detonula) attained numbers of 784 and 1700 per ml at the two shoreward stations, but thereafter dropped to well below 500, then to 48 or less per ml. However, such occurences are seldom encountered.

Consistent knowledge of the nitrate and orthophosphate values for these surface waters is not available. A few determinations were made for Florida Power and Light Company to compare Biscayne Bay and this area of shelf water, and they were low - very low. To explain the low population figures values of these nutrients should have been obtained. From a practical standpoint, the populations probably indicate extremely small increases of nitrate and orthophosphate. Lacking accurate figures for these, definite proof is not available. There could be other reasons such as toxicants in the outcoming sewage or insufficient dilution of the sewage, but generally where sewage discharge noticeably increases nutrients, the increase is reflected in higher plankton counts. Where the Boca Raton area has shoreward numbers consistently below 300 per ml, Tampa Bay numbers run above 2500 per ml and Escambia Bay above 5000 per ml. These two locations are known to be high in nitrate and phosphate in the Gulf Stream, again for comparative purposes. These values are well below 0.1 ppm of nitrate and 0.01 of phosphate. In November 1969, two Gulf Stream Stations, 12000 and 17000 feet off Pompano Beach, and at a temperature of 77° F. had 36 and 54 organisms per ml respectively. On August 5, 1968, the most distant three samples were in the Gulf Stream, the last 30000 feet offshore. They contained 70, 33 and 38 organisms per ml.

Table 10

Species of microscopic algae and protozoa recorded from 181 samples representing four environmental niches in the Boca Raton area from 1967 to 1969.

Niche	Transect	Gulf Stream	Interface	Slide
No. Samples	73	28	60	20
Organisms	Number occurrences			
Sulfur bacteria				
Achromatium oxaliferum			25	
Beggiatoa alba			17	
Beggiatoa arachnida			29	
Beggiatoa gigas			4	
Beggiatoa leptomitiformis			6	
Beggiatoa minima			1	1
Beggiatoa mirabilis			10	
Thioploca sp.			1	
Thiorhodacene, various			1	
Thiospirillum sp.			1	
Thiothrix niveus			5	
Thiovulum majus			6	
Green algae s.s. - Chlorophyceae				
Chlorella sp.	9			
Halosphaera sp.	1			
Green cells, minute	49	16		6
Blue green algae				
Agmenellum sp.			2	
Anabaena sp.	5		5	
Anacystis sp.			5	
Arthrospira sp.	1		7	1
Borzia trilocularis				1
Fremeyella violacea				1
Johannesbaptistia pellucida			5	
Lyngbya, 10 m. diameter, red			18	1
Lyngbya, 25 m. diameter, red			12	1
Lyngbya, 60 m. diameter, red			9	
Merismopedia sp.		1	8	1
Oscillatoria sp.	5		20	2

Niche	Transect	Gulf Stream	Inter-face	Slide
Blue green algae, con't				
Richelia intracellularis		1		
Schizothrix calcicola	3		5	3
Skugaella sp.	13	8		
Spirulina major			3	1
Spirulina minor			5	1
Green flagellates - Volvocida				
Bipedinomonas rotunda	3	2		
Bipedinomonas pyriformis	2	1	2	
Chlamydomonas marina			4	
Chlamydomonas sp.				1
Dunaliella-viridis?	14	2	2	
Monochrysis lutheri?		1		
Oltmansiella lineata	1		1	
Platymonas sp.	1			
Pyramidomonas disomata	3		1	
Pyramidomonas grossi	31	3	5	1
Pyramidomonas octociliata	1		1	
Pyramidomonas sp.		3	3	
Green flagellates - Euglenida				
Anisonema grande			6	
Anisonema emarginatum			9	
Anisonema lateralis, p.n.			1	
Anisonema lineata, p.n.			3	1
Anisonema orbicularis	1		4	
Anisonema ovale			29	2
Anisonema variable			3	
Anisonema sp.			7	
Cylindromonas floridensis, p.n.			4	
Cymbomonas sp.?			1	
Dinema grisoleum			11	
Distigma proteus			3	
Entosiphon caudata p.n.			4	
Entosiphon cuneatum			3	
Entosiphon obliguum			2	
Entosiphon ovale, p.n.			3	
Entosiphon polyaulax			1	
Entosiphon salcatum			1	
Euglena floridensis, p.n.			1	
Euglena sp.	1		7	
Eutreptia sp.	13	1	13	
Eutreptiella sp.			1	
Hyalophacus sp.			1	
Jenningsia diatomophaga			1	
Khawkinea ocellata			1	
Notosolenus apocamptus			1	

Table 10, continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Green flagellates - Euglenida, con't				
Notosolenus orbicularis			1	
Peranema granulifera			2	
Peranema trichophorum			4	
Petalomonas carinata			5	
Petalomonas papilio			1	
Petalomonas pusilla			5	
Petalomonas spinosus, p.n.			1	
Petalomonas sp.			1	
Pleotia vitrea			4	
Scytomonas pusilla			4	
Sphenomonas elongata			5	
Sphenomonas teres			9	
Tropidoscyphus octocostatus			2	
Urceolus sabulosus			1	
Olive-green, brown or red flagellates - Cryptomonadida				
Chilomonas marina	2	2	5	
Chroomonas spp	9		2	3
Cryptomonas erosa			14	
Cryptomonas marina, p.n.			18	
Cyathomonas truncata			1	
Hillea spp	11		1	
Rhodomonas baltica	3		1	
Rhodomonas sp.	19	1	14	7
Yellow or brown flagellates-Chrysomonadida				
Chrysamoeba sp.	2			
Chrysochromulina spp.	36	6	2	2
Olisthodiscus luteus	1		1	
Calcareous, yellow flagellates - Coccolithophorida				
Acanthoica schilleri	1			
Acanthosolenia sp.		1		
Discosphaera thompsoni	4			
Rhabdosphaera sp.	3	2		2
Syracosphaera carteriae	42	13		
Syracosphaera sp.		2	2	
Silicious flagellates-Silicoflagellida				
Dictyocha fibula		1		
Ebria tripartita	2			
Green flagellates - Chloromonadida				
Chattonnella subsalsa			3	

Table 10, continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Green flagellates - Chloromonadida, con't				
Gonyostomum sp. (?)			1	
Thaumatomastix flava, p.n.			3	
Thaumatomastix glauca, p.n.		1	8	
Trentonia flagellata			1	
Vacuolaria virescens			1	
Dinoflagellates - Dinoflagellida				
Amphidinium acuta			3	
Amphidinium bipes			20	
Amphidinium brittanicum			1	
Amphidinium crassum	1	1		
Amphidinium depressum, p.n.	2		25	
Amphidinium herdmanni			2	
Amphidinium klebsii			31	6
Amphidinium kofoidi			2	
Amphidinium latum	12	3	3	
Amphidinium longum	1	1	2	
Amphidinium operculatum			11	1
Amphidinium roseolum			7	
Amphidinium rugosa, p.n.			1	
Amphidinium scissum			3	
Amphidinium spinosum, p.n.			1	
Amphidinium sp.			25	1
Ceratium belone	1	2		
Ceratium candelabrum	1	4		
Ceratium concilians		2		
Ceratium furca	6	5		
Ceratium fusus	2	5		
Ceratium gibberum		1		
Ceratium horridum		1		
Ceratium karsteni		1		
Ceratium lineatum		1		
Ceratium massiliense	3	6		
Ceratium minuta	4	4		
Ceratium setaceum		1		
Ceratium tripos	3	7		
Ceratium sp.		3		
Ceratocorys, sp. 1	1	4		
Ceratocorys, sp. 2	1	4		
Cochlodinium schuetti	7	2		
Dinophysis tripos	2	2		
Diplopsalis lenticula	3	7	1	
Diplopsalopsis	11		2	
Entomosigma	2		2	
Exuviaella apora			10	

Table 10, continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Dinoflagellates - Dinoflagellida, con't				
Exuviaella marina	1		30	1
Exuviaella sp.	1	13		
Goniodoma polyedricum	1	2	1	
Gonyaulax diegenesis	1		1	
Gonyaulax triacantha	14	4		
Gonyaulax sp.	2	3		
Gymnodinium alba, p.n.	12	5	5	
Gymnodinium albulum	17	2		
Gymnodinium breve (?)	1			
Gymnodinium conicum			1	
Gymnodinium flavum	1			
Gymnodinium longum, p.n.	1	1		
Gymnodinium mirable	4			
Gymnodinium oculatum, p.n.			1	
Gymnodinium punctatum	2			
Gymnodinium pygmaeum	3	1	3	1
Gymnodinium splendens	2		2	
Gymnodinium simplex	4	3	2	
Gymnodinium uberrimum	2		5	
Gymnodinium variable		1	2	
Gymnodinium sp.	20	5	26	2
Gyrodinium crassum			2	
Gyrodinium pingue	7	1	4	
Gyrodinium sp.	4		4	
Histoneis	1	1		
Massartia rotundata	6		3	
Massartia sp.	9	1	5	
Nematodinium	3			
Ornithocercus magnificus		2		
Ornithocercus sp.	1	5		
Oxyrrhis marina			1	
Oxytoxum scolopax		2	1	
Peridinium cerasus	3		1	
Peridinium depressum	2	2		
Peridinium divergens	2			
Peridinium globulus	5		1	
Peridinium longa	6	3		
Peridinium triqueter	1	2		
Peridinium trochoideum	12	1	2	
Peridinium tubus		1	1	
Peridinium sp.	4	3		
Phalacroma argus			2	
Phalacroma cuneata		1		
Phalacroma rosea			9	
Phalacroma sp.		2		
Podolampas bipes	1	3		

Table 10, continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Dinoflagellates - Dinoflagellida, con't				
Podolampas palmipes	2	1		
Polykrikos schwartzi		1	1	
Pronoctiluca pelagica	1	1		
Protoceratium reticulatum	1	1	3	
Protodinium sp.	27			
Prorocentrum gracile	2			
Prorocentrum micans	3		2	1
Prorocentrum scutillum			2	
Prorocentrum triangulatum	7	2		
Pyrodinium bahamiense	2			
Pyrophacus horologicum	3	3		
Thecadinium kofoidi			25	
Thecadinium spinosus, p.n.			1	
Torodinium robustrum	4	5	2	
Diatoms - Bacillariophyta				
Actinoptychus undulatus			3	
Amphora ovalis	3		31	2
Amphora superba, p.n.			7	2
Amphiprora minor, p.n.	1			
Amphiprora sp.	4		25	
Asterionella japonica	2	1	12	
Asterionella kariana		1	10	3
Biddulphia aurita	8		10	3
Campylosira cymbelliformis	1		7	
Chaetoceras atlanticus	2			
Chaetoceras curvisetus			1	
Chaetoceras decipiens	11	1		
Chaetoceras galvestoniensis	3	1	8	
Chaetoceras solitaria	13	1	1	
Chaetoceras unispinosus, p.n.	3			
Chaetoceras sp.	13	7	6	
Cocconeis spp.	3		14	6
Corethron hystrix			2	
Coscinodiscus concinnus			4	
Coscinodiscus socialis	1			
Coscinodiscus sp.	12	4	7	1
Cyclotella spp.	35	6	1	
Cymbella sp.		1	5	
Detonula sp.	41	8		
Diploneis minor, p.n.			5	
Diploneis sp.	2		25	
Diatoma sp.			3	

Table 10 continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Diatoms - Bacillariophyta, con't				
Eunotia sp.				1
Granematophora sp.		1		
Guinardia flaccida	7	1	1	
Gyrosigma angusta, p.n.	5		24	5
Gyrosigma sp.			20	
Hemiaulus haucki	9	3	3	
Hemiaulus membranaceus	1	1	1	
Hemiaulus sinensis	7	6		
Lauderia borealis			1	
Leptocylindrus danicus	11	1		
Licmophora abbreviata	3		6	8
Licmophora sp.	1			8
Lithodesmium undulatum	2		8	
Melosira sulcata	2		16	
Melosira sp.	1			
Navicula ostrea			1	
Navicula van houteni			21	
Navicula viridis			2	
Navicula spp.	57	8	48	19
Nitzschia closterium	54	12	39	13
Nitzschia formosa			6	
Nitzschia recta			3	
Nitzschia seriata	63	13	13	
Nitzschia sigmoidea			24	
Nitzschia longissima	4		18	2
Nitzschia paradoxa			27	
Pinnularia sp.		1		
Pleurosigma sp.	6		31	
Rhizosolenia alata	1			
Rhizosolenia delicatula	15			
Rhizosolenia fragilissima	3	1	1	
Rhizosolenia fragilissima	2	3		
Rhizosolenia hebetata	1			
Rhizosolenia setigera	18	5	1	
Rhizosolenia stolterforthi	5	1	1	
Skeletonema costatum	63	11	22	3
Spathyneis mobilis, p.n.	1		27	
Stephanopyxis turris			4	
Streptotheca thamensis			8	
Striatella unipunctata			2	1
Synedra longa, p.n.	1		1	
Synedra ulna	1	1	1	
Synedra undulatus			5	3
Synedra sp.	3	1		2

Table 10, continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Diatoms - Bacillariophyta, con't				
Surirella sp.	1		1	
Tabellaria fenestrata			1	3
Thalassiosira rotata		1		
Thalassiosira sp.	16	3	1	
Thalassiothrix sp.	4	1	1	
Tropidoneis lepidoptera	1	1	43	
Tropidoneis minor, p.n.	1	1	2	
Tropidoneis sp.			4	
Zoomastigophorea				
Bicocca mediterranea	5			
Bodo agilis	4	1	8	6
Bodo celer, p.n.	1		8	1
Bodo globosa			2	
Bodo marina			2	1
Bodo reniformis, p.n.				4
Bodo rugosa, p.n.	1			
Bodo sp.	1		2	2
Calycomonas ovale	3			
Cercobodo sp.	3		4	
Ciliophrys marina	1			
Craspedomonadida	1	3		
Dinomonas vorax		2		
Hasleya sp., p.n.	4	1		
Monas sp.	2		1	1
Multicilia lacustris	1			
Oicomonas termo			6	
Oicomonas sp.				
Phanerobia pelophila		1		
Pleuromonas radians, p.n.			4	
Pleuromonas saltans, p.n.			1	
Protospiromonas sp., p.n.	20	4	4	
Rynchobodo nasuta			1	2
Spiromonas angusta	2		5	
Sterromonas formicina		2		
Zooflagellata, unid.	53	14	39	8
Rhizopodea				
Actinaria spp.	5	11		
Actinophrys marina				1
Amoeba spp.	1		5	
Amoebulae spp.	1			
Amphitrema elongata			1	
Arachnula			1	
Foraminifera spp.			24	1
Globigerina spp.	3		4	

Table 10, continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Rhizopodea, con't				
Gromia oviformis			11	
Gymnophrys cometa			3	
Heleopera			1	
Heliozoa spp.		1	5	
Pelomyxa sp.			1	
Radioleria spp.		4		
Raphidiophrys pallida			3	
Raphidiophrys sp.			2	
Shepheardiella taeniformis			2	
Vahlkamphia albida			2	
Vahlkamphia guttula			1	
Vahlkamphia limax			1	
Vampyrella laturitis			1	
Unid. testate rhizopods	1		1	
Ciliata				
Acanthostomella sp.		1		
Albatrossiella filigera	1			
Amphisia sp.			2	
Amphorellopsis (mexicana?)	4	2	1	
Aspidisca costata			3	
Aspidisca hexeris			15	1
Aspidisca lynceus	2		5	
Aspidisca steinii			1	
Aspidisca turrita			1	
Aspidisca sp.			4	
Chaenea gigas			7	
Chaenea teres			2	
Chaenea sp.			3	
Codonella sp.	2	1		
Codonellopsis sp.	1	2	3	
Coleps amphicanthus			1	
Coleps hirtus			4	
Coleps pulcher			2	
Coleps sp.			7	
Condylostoma (patens?)			4	
Condylostoma sp.			1	
Cothurnia sp.			1	
Cristigera phenix			6	
Cryptopharynx rugosa, p.n.			5	
Cryptopharynx stigerus			9	
Cyclidium sp.		1	19	
Dadayiella ganymedes			1	
Diophrys appendiculata			8	
Diophrys triangulata, p.n.			2	

Table 10, continued

Niche	Transect	Gulf Stream	Inter-face	Slide
Ciliata, con't				
Diophrys sp.			2	
Drepanomonas spinosus, p.n.			3	
Dysteria aculeata			1	
Dysteria monostyla			1	
Dysteria olivaccum			1	
Dysteria sp.			3	1
Epiclintes ambiguus			4	
Epiplocylis blanda	1	2		
Euplotes minima			10	
Euplotes vannus			2	
Euplotes sp.			5	
Favella panamensis	1			
Favella sp.	2	2		
Frontonia marina			3	
Gastronauta membranaceus				
Geleia decolor			1	
Geleia floridensis			1	
Gruberia sp.			1	
Hemiophrys sp.			8	1
Holophrya sp.			1	
Holosticha discocephalus			5	
Holosticha fasciola			1	
Holosticha flava, p.n.			1	
Holosticha ovalis			1	
Holosticha violacea			1	
Holosticha sp.			2	
Hypotrichida, unid. spp.			9	
Kentrophoros lanceolata			19	
Lembus fusiformis			6	
Lembus infusionum			3	
Lionotus sp.			1	
Loxophyllum maleagris			1	
Mesodinium acarus	1		7	
Mesodinium cinctum	1		5	
Mesodinium rubrum	2		4	
Metacystis truncata			7	
Oxytricha discocephalus			3	
Oxytricha fallax			1	
Oxytricha sp.	1		11	1
Parablepharisma sp.			1	
Parafavella (elegans?)		1		
Peritromus californicus			3	
Peritromus emmae			1	
Peritromus faurei			5	
Peritromus montana			1	
Peritromus rugosa, p.n.			4	

Table 10, continued

Niche	Transect	Gulf Stream	Inter- face	Slide
Ciliata, con't				
Peritromus sp.				
Pleuronema marina			5	
Podophrya fixa				2
Prorodon sp.			1	
Protocrucia pigerrima			5	
Protocrucia sp.			1	
Protorhabdonella sp.		1		
Pseudoprorodon arenicola			1	
Remanella margaritaceum			1	
Remanella rugosa			5	
Remanella sp.			4	
Rhabdonella (hebe?)	2	3		
Saprophilus agitatus			1	
Steinia marina				
Stentor auriculata			1	
Stephanopogon colpoda			3	
Stichotricha secunda			3	
Strobilidium sp.	4	1	4	
Strombidium conicum			1	
Strombidium sp.	4	1	9	
Telostoma ferroi			1	
Tintinniduum primitivus	1	1		
Tintinnopsis minuta	17	3		
Tintinnopsis platensis	1			
Tintinnopsis prowazeki	2	1		
Tintinnopsis rotundata	1	1		
Tintinnopsis subacuta			1	
Tintinnopsis sp.	3	1	1	
Tintinnus pectinis	1	1		
Tintinnus sp.	1	2		
Tintinnidae, unid sp.	4	2		
Tontonia appendiculata			1	
Trachelocerca coluber			11	
Trachelocerca phoenicopterus			27	
Trachelostyla sp.				
Trochilia salina			3	
Trichopelma torpens			3	
Uroleptus mobilis			1	
Uroleptus rattulus			3	
Uroleptus sp.			2	
Uronema filificum			1	
Uronema marina			1	
Uronychia setigerus			12	
Uronychia sp.			3	
Urostyla caudatus			1	
Vorticella sp.	1	3	1	
Zoothamnium		1		

On the basis of transect samples during the past two years, the plankton numbers reflect no increasing fertility of the surface waters in the area Hollywood to Delray Beach. Species which are characteristic of recent organic pollution are exceedingly rare. Total species per sample are few, and both species and numbers are characteristic of impoverished shelf water. In addition they are similar to those of Hutchinson Island shelf water, and to some extent of lower Biscayne Bay, both of which are nutrient poor.

SEDIMENT-WATER INTERFACE STUDIES

In water which is not too turbulent or too shallow, particulate organic matter such as sewage particles or the debris of dead organisms, usually sink to the bottom and there are mineralized by biological action. It was thought that introduced sewage might have a fallout in the area where released even though the plume rose to the surface in 90 feet of water, and was dispersed by wind and tidal currents. Accordingly SCUBA divers were employed to bring up samples of the interface, both near the sewer outfalls and from places far removed.

Divers carried rigid plastic (thick walled) tubes about 15-24 inches long to the bottom at depths of 15 to 150 feet. There the tube was jammed into the bottom, so that if possible the top of the core was not less than six inches from the top of the tube. The top was stoppered, then the bottom. If the sand or silt was loose and uncompacted, the tube could be leaned to one side and then the bottom stopper inserted. It may not be generally realized, but this usually obtains an undisturbed interface, since the top tends to be crusty except in quite coarse sand and shell fragments.

These tubes are brought into the laboratory in a bucket of water, protected from the sun, and the top stopper removed, care being taken to assure no leak at the bottom. Usually water is pipetted off until only about an inch remains over the core. Examination of this pipetted water shows usually a biota similar to the surface water, but with some bottom organisms. The cores are viable for 24-48 hours, and actually the interface biota is best represented after several hours standing in the laboratory.

The interface, about 1.4 millimeters thick, is an amazing microcosm. Its microbiota is far more similar, sample to sample, than the macrofauna of much larger samples of bottom material. Examination is simply by taking a succession of drops of mixed water and surface material, spreading beneath a cover glass and examining at 100 and 400 diameters. A rough quantitation is possible by estimating the number of drops in a 2 or 3 millimeter interface for the tube diameter, then counting the organisms in each of several drops. In a silt or very fine sand interface counting is not too difficult, except for movement by the organisms. But in coarse sand or shell debris it is all but impossible, so tenaciously do the organisms cling to the grains or fragments. Some such as the diatom Cocconeis or certain blue green algae are actually attached to the grains. Attempts at dislodging the organisms by flushing out with ice cold fresh water, back flushing and agitation, have been futile. Removal of the finer suspension after gentle agitation and about a two second lapse for coarse particle settling has been partly successful, especially if the fine suspension is centrifuged gently for about three minutes.

Table 10 indicates that some surface organisms are found in the interface. Their occurrence there is very limited both as to number and as to species. Actually the two groups are distinctive. The shelf water plankton typically includes a few volvocids, a few cryptomonads and coccolithophorids, certain dinoflagellates, diatoms and swimming ciliates all with organelles for swimming, or in the diatoms, flotation mechanisms. There is a sharp difference also between the shelf plankton and the Gulf Stream plankton. The interface organisms are principally creeping organisms - sulfur bacteria, some blue green algae which are red in color, colorless euglenids, characteristic dinoflagellates, many pennate diatoms, a great variety of ciliates and a few rhizopods - thecate forms mostly, and exclusive of the globigerinids, acantharians and adiolarians of the Gulf Stream. There are exceptions of course - the shelf surface water often contains the blue green alga Richelia, epiphytic Rhizosolenia, and a species of the ciliate Vorticella, epizoic also on diatoms. But the largest ciliates such as Trachelocerca, Stentor and Condylostoma are interface organisms.

The abundance of ciliates attests to the high population of bacteria there; the saprozoic euglenids to the release of soluble organic matter; the sulfur bacteria to the abundance of sulfides; and the many photosynthetic diatoms and dinoflagellates to the release of nitrate and phosphate. The red color of many indicates the filtered-out portion of the spectral light even at 150 feet.

For many of these no satisfactory taxonomic placement was possible. Some are certainly undescribed species, but time has not yet allowed a literature search for most of them. Because of this a number have the designation p.n. in Table 10, denoting a handy provisional name for purposes of enumeration as they recur.

The very numbers of interface organisms is an indication of how important is this interface as a place where mineralization is very active. Many of the organisms there are facultative, but very few are found below about the three millimeter depth in the sediment.

BUILD-UP BENEATH OUTFALLS

For some time now, black mounds have built up beneath the Pompano Beach and Delray outfalls. The mounds and surrounding periphery fluctuate in height and perimeter usually being no more than three feet high and perhaps fifty feet or less long, twenty or thirty wide. They are semi-permanent, subject to current attrition. *They are the first indication of a sewer outfall effect in this area*.

They are inhibitory to the normal interface biota, at their location. The only microscopic interface organisms found on them are bacteria, a few colorless flagellates (*Bodo*, *Trepomonas*, *Monas* and *Oicomonas*) and a few large ciliates. Thus on December 9, 1969, the following 17 organisms were recovered from the interface of the mound beneath the Pompano Beach outfall:

- Sulfur bacteria
  - *Beggiatoa alba*

- Zooflagellata
  - *Bodo marina*
  - *Trepomonas rotans*
  - Unidentified species

- Ciliata
  - *Condylostoma*
  - *Gastronauta*
  - *Gruberia*
  - *Hemiophrys*
  - *Loxophyllum*
  - *Oxytricha*
  - *Peritromus*
  - *Trachelocerca coluber*
  - *Trachelocerca phoenicopterus*
  - *Uronychia*
  - *Unidentified species*

- Metazoa
  - *Polychaeta*
  - *Copepoda* (harpacticoid)

Seven of these were not found in any of four cores surrounding this mound at approximately 100 foot distances from it. Only two of them were found in all five cores. Yet the outer four cores yielded 75 other species in the time available for their study. (A fairly comprehensive analysis of a core interface required two to four hours.) Other examinations of these mounds at other times generally produced the same results: a black deposit, harpacticoid copepods and a few species, but often large numbers, of ciliates. Curiously they not infrequently contained, in each 2-inch core, a few emphipods, and capitellid worms, such as Reish has found around the California outfalls.

The inhibitory effect on the normal bottom biota and the normal process of mineralization is clear. A large area blanketed by such a deposit would not only have this effect, but also a serious effect on the food chain. It was pointed out above that such shelf waters are impoverished, i.e., low producers, and they could stand more production of microscopic plants and animals to fatten the food chain. And if sewage contains N and P, why not use it? The process of mineralization in these mounds is almost certainly anaerobic, despite our lack of DO measurements there. This means it is slow.

Yentsch in his analysis of December 29, 1969, suggests the possibility of the diatom population being augmented in the vicinity of outfalls by fertilization. This does not occur, either for diatoms, photosynthetic dinoflagellates, or saprozoic euglenids; all three groups being very abundant at points far removed from outfalls. Since figures for nitrogen and phosphorus are more than open ocean, or offshore shelf waters, and since Yentsch believes these values reflect those in the sludge mounds, it seems reasonable to expect higher photosynthetic populations. This does not occur; instead there is a lowering of the population, with no suitable explanation available. Blackening of the sand and the types of organisms present indicate an anaerobic process, and it is probable that what mineralization occurs is due to bacteria, and that not enough fertilizer is released to increase either plankton or interface organisms.

SLIDE EXAMINATIONS

Neither the plankton nor the interface studies provided much of a clue to organisms capable of attaching to a solid substrate and forming colonies there. Some few colonies of Zoothamnium and a few colonial diatoms were noted, but nothing like the folonial ciliates important in sewage treatment. Accordingly rectangular racks were constructed which would hold a dozen microscope slides at top and bottom, and which were open on both sides. Some of these racks were attached to the sewer outfall, some to the current meter, far distant from any sewage. Numbered slides were inserted and left for 24, 48 and 72 hours. At the end of these intervals, the slides or the entire rack were removed, placed in a bucket or other container of water, and brought in. One side was wiped off, and a cover glass was placed on the middle of the other side. The slide could then be examined at 100 and 400 diameters, and organisms in 625 millimeters could be identified and counted.

Much of the evidence from these studies was negative. The slides from the outfall conduit simply did not acquire a high population, even at the end of 72 hours. It had been expected that after 24 hours a bacterial film would be present along with numerous zooflagellates of the genera Bodo, Monas, and Oicomonas, and some ciliates. The bacterial film developed, but very little else, even after 72 hours. From the number of times this was repeated it appears as if the plume of sewage is inhibitory, either from its composition or by creating a strong vertical current.

At the current meter the slides were more productive. Few organisms accumulated, even after 72 hours, near the surface (20-30 feet), but near the bottom a more varied and numerous biota developed. Often the slides were too overgrown at 72 hours to count.

This biota was an ecologic group. First to appear were bacteria, then zooflagellates and the ciliates *Dysteria* and *Chilodonella*. Then naviculoid diatoms appeared, and seemed to reproduce and remain on the slide. There was some mixture of diatom species eventually, but beautiful colonies of *Licmophora*, an unidentified arcuate species, and *Asterionella kariana* usually dominated. On some slides almost the only organism was the suctorian *Podophrya* posing the question of whether or not it fed on diatoms. After 72 hours the slides were frequently overgrown with diatoms, hydroids, nematode worms, and hypotrichous ciliates had also appeared. *Asterionella kariana* was virtually unknown in these studies until it appeared on the slides. The same is true of *Podophrya*. Apparently there is a separate environmental niche for such attaching organisms. However these slides rather present an academic than a practical interest, aside from the possible inhibitory action of the sewage plume.

SHELF VERSUS GULF STREAM PLANKTON BIOTAS

Almost the only green, non-motile cells found in this work occurred as plankton at the near shore stations. The inshore waters out to depths of more than 100 feet often contained a few pennate diatoms, and such species as *Asterionella japonica*, certain species of *Chaetoceras*, *Rhizosolenia* and small centric forms. Actually most of the species listed by Cupp for the area around La Jolla, California, or the Pudget Sound area, occurred here despite the much warmer water. The greatest difference was in the low numbers of large centric diatoms near Boca Raton.

Euglenids were almost lacking. Cryptomonad genera showed several species of *Cryptomonas*, *Chilomonas*, *Rhodomonas*, and *Hillea*, occasionally in large numbers. Volvocida were restricted almost wholly to *Pyramidomonas grossi*. Large dinoflagellates were scarce but small species of *Gymnodinium* and *Gryodinium* occurred. Coccolithophorids were represented almost wholly by *Syracosphaera carterae*. Other groups were occasional, except a few tintinnids occurred with some frequency, but not abundance, likewise Strombidium.

The Gulf Stream not only had much smaller numbers - there were fewer species and they were different. This is shown in Table 10, and it applies especially to Coccolithophorids, Acantharia, and Radiolaria. Such mixing of shelf and Gulf Stream species as occurred was usually more than 6000 feet offshore. It was found that water bottle samples in the Gulf Stream gave a poor picture of its biota, so a Clarke-Bumpus sampler using a No. 20 net was employed. This was towed at the surface, at 30 feet, at 100 and at 200 feet. The numbers of organisms in the top meter and at 30 feet was about the same, but there were fewer at 100 feet, and very markedly less at 200 feet. This was true of virtually all species; there was no stratification of copepods at any of these four depths.

Only a few species of Radiolaria were encountered; but Acantharia, though unidentified, were quite diverse. Ciliates were mostly tintinnids - a few species, rare in occurrence. It was found that if the net was towed a short time, and the catch was washed into 800 or 1000 mls of water, there was no quick die off, so that species were studied alive. Unfortunately, Acantharia preserved very poorly, even with 3-5% formalin.

CONCLUSIONS

Table 10 is quite informative in regard to the quality of organisms in the four ecological situations involved. First, it provides an idea of abundance, because of three of these situations, and with few exceptions, the fourth, the organisms listed were encountered in one ml. of water, i.e., in any ml. of raw water the organisms occurred at least once, for a particular sample. The number of occurrences as shown in columns 1, 2, 3 and 4 also gives an idea of frequency of occurrence, but not whether the organism is seasonal. The table does not give information as to the total numbers of each species on any date, and hence little idea of population density. This would have to be determined from the individual reports, and there is little to be gained from an attempted average of these, since one species may occur in relatively large numbers on one date, and a different species on another date. It has been stated above that blooms are virtually lacking in the transect samples and that the numbers in the interface are large - perhaps 18,000 to 24,000 diatoms in some samples, with 100 to 1600 colorless euglenids and the same number of ciliates per ml. Trichodesmium (Skujaella) may bloom in the Gulf Stream, and is certainly the dominant organism there.

Table 10 also graphically separates the free floating from the creeping organisms, and the consumers of bacteria (ciliates) from those more dependent on photosynthesis. This is not so clear-cut because light penetrates the depths at which the outfalls were located in sufficient quantity to affort phytosynthesis. Its lessened effectiveness is shown, however, in the red color of the blue green algae and dinoflagellates at these depths.

This separation also indicates the nature of the processes which occur at the various depths. Thus the surface waters of the transects have 25 species of ciliates, most of them tintinnids, and the Gulf Stream 20. These are probably obligate aerobes, feeding on bacteria. The interface ciliates number 99, many of them facultative aerobes, but also feeding largely on bacteria. The indication is that bacteria are few in the surface waters, abundant in the interface. But the euglenids and colorless dinoflagellates of the interface, some of which are facultative aerobes, also indicate that soluble organic matter is being liberated here, whereas the surface waters are impoverished of both inorganic and soluble organic matter. And the only indication of any sewage effect is directly beneath the outfalls, where the numbers of all organisms are greatly reduced.

RECOMMENDATIONS FOR FUTURE STUDIES

The analyses furnished do not give the organic content of the cores beneath the outfalls or distant therefrom. It is recommended that any future studies do this on a dry weight-ash basis. It is recommended also that an effort be made to determine H_2S in these cores, since this gas is toxic. If the blackening of the particulate matter is due to metallic sulfides, H_2S becomes of less importance. Nevertheless, if the cores are left stoppered, the organisms die, and H_2S is nasally detectable. This indicates a goodly amount of organic matter. If these black mounds build up, the buried organic matter will be mineralized with great slowness.

It is also recommended that an oxygen probe be used, since H_2S and O_2 are compatible in small amounts. But the two sets of data for nitrogen and phosphorus are not sufficient, beyond indicating that more than normal are actually released. However NO_3^-/N was lacking in the cores both beneath the outfall and 100 feet away, as well as immediately above the Pompano core on September 29, 1969. $PO_4^{\equiv}$/P was much higher in the supernatant water than in the cores. Such an unbalanced condition is not conducive to high biotic production. A conspicuous weakness of these studies is that not enough chemical data was amassed to find correlations with the biotic data, but this was not possible under the working conditions and time available.

SECTION VI

OCEANOGRAPHIC FEATURES OF NEARSHORE WATERS ON A NARROW CONTINENTAL SHELF

INTRODUCTORY COMMENTS

Ocean outfalls are being utilized to dispose of human waste by ocean fringing communities throughout the world. The economic benefit of disposing sewage with little treatment through use of outfalls is being justified by the assumptions that: (1) the ocean is vast and therefore capable of dispersing and diluting the discharge without degradation of water quality; (2) sea water die-off of pathogenic bacteria is very rapid so that public health standards are not violated; (3) bacterial breakdown and recycling of wastes will occur without significant buildup of organic material. These three assumptions cannot be applied uniformly to all outfall locations for they are dependent upon a particular localities oceanographic features.

It is not the ocean as a whole that is receiving the discharged wastes, but rather the nearshore waters. Therefore, the oceanographic environmental parameters associated with each outfall side will control the short and long term effects of wastes disposal into the nearshore receiving waters. The environmental parameters will control the spacial and temporal movements of the effluent field after discharge into the nearshore waters. Physical parameters such as current speed and direction, wind speed and direction, temperature, salinity and their associated horizontal and vertical distributions will determine whether or not the effluent will surface, how it will disperse, how long it will remain in the area, and the magnitude of natural bacteria die-off.

Florida Ocean Sciences Institute has been investigating, for the past three yeras, the oceanographic parameters of the nearshore waters off Pompano, Boca Raton, and Delray as related to the Pompano and Delray outfalls (Figure 22). These outfalls discharge at a water depth of 90 feet as will the Boca Raton outfall when construction is completed. By classical definition this water depth is defined as the "edge" of the continental shelf or the point where the bottom profile gradient increases to 1 foot in the vertical for every 20 feet horizontal.

The nearshore circulation off Pompano, Boca Raton, and Delray departs from the typical shelf water movements which are controlled by tide and wind forces for two significant reasons; the extreme narrowness of the continental shelf (1 - 1½ miles in width) and the close proximity of the Florida Current (Gulf Stream). The western edge of the Florida Current meanders laterally (east-west) causing large fluctuations of current speed and direction in the shelf waters which mask wind and tide induced variations. The interaction of the Florida Current

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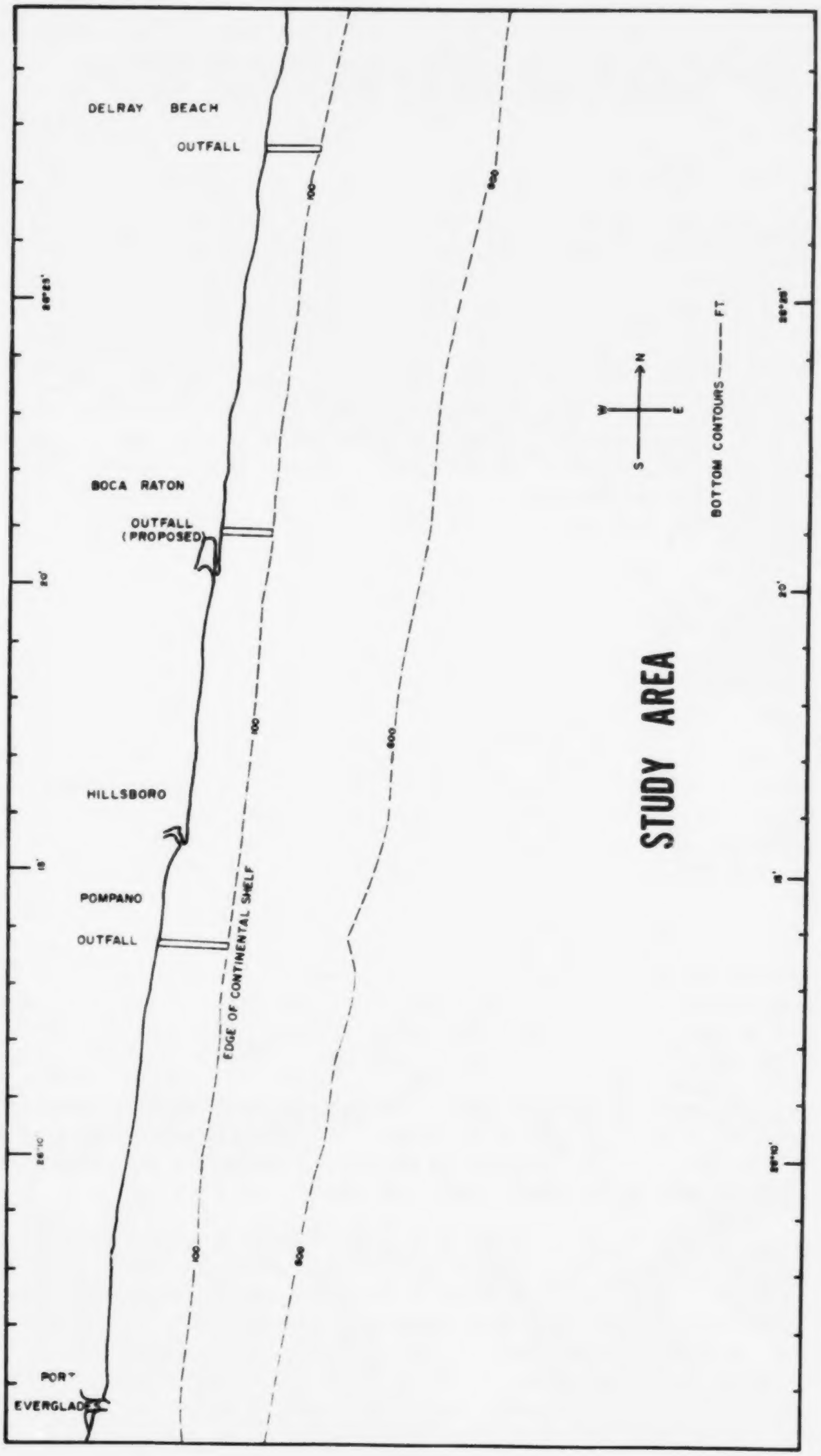

DELRAY BEACH
OUTFALL
BOCA RATON
OUTFALL
(PROPOSED)
HILLSBORO
POMPANO
OUTFALL
PORT
EVERGLADES
EDGE OF CONTINENTAL SHELF
100
600
STUDY AREA
BOTTOM CONTOURS —— FT
N
S
E
W
26°25'
20'
15'
26°10'

FIG.22

with its land boundary at the Continental Shelf produces large cyclonic eddies in the shelf waters that are entrained northward by the Florida Current and further complicate the nearshore circulation. The major oceanographic features of the nearshore waters off Pompano, Boca Raton, and Delray in general will typify the continental shelf waters of Southeast Florida. Differences may occur as the Continental Shelf widens enabling tide and wind forces to exert more influence on the water further removed from the Florida Current.

INSTRUMENTATION

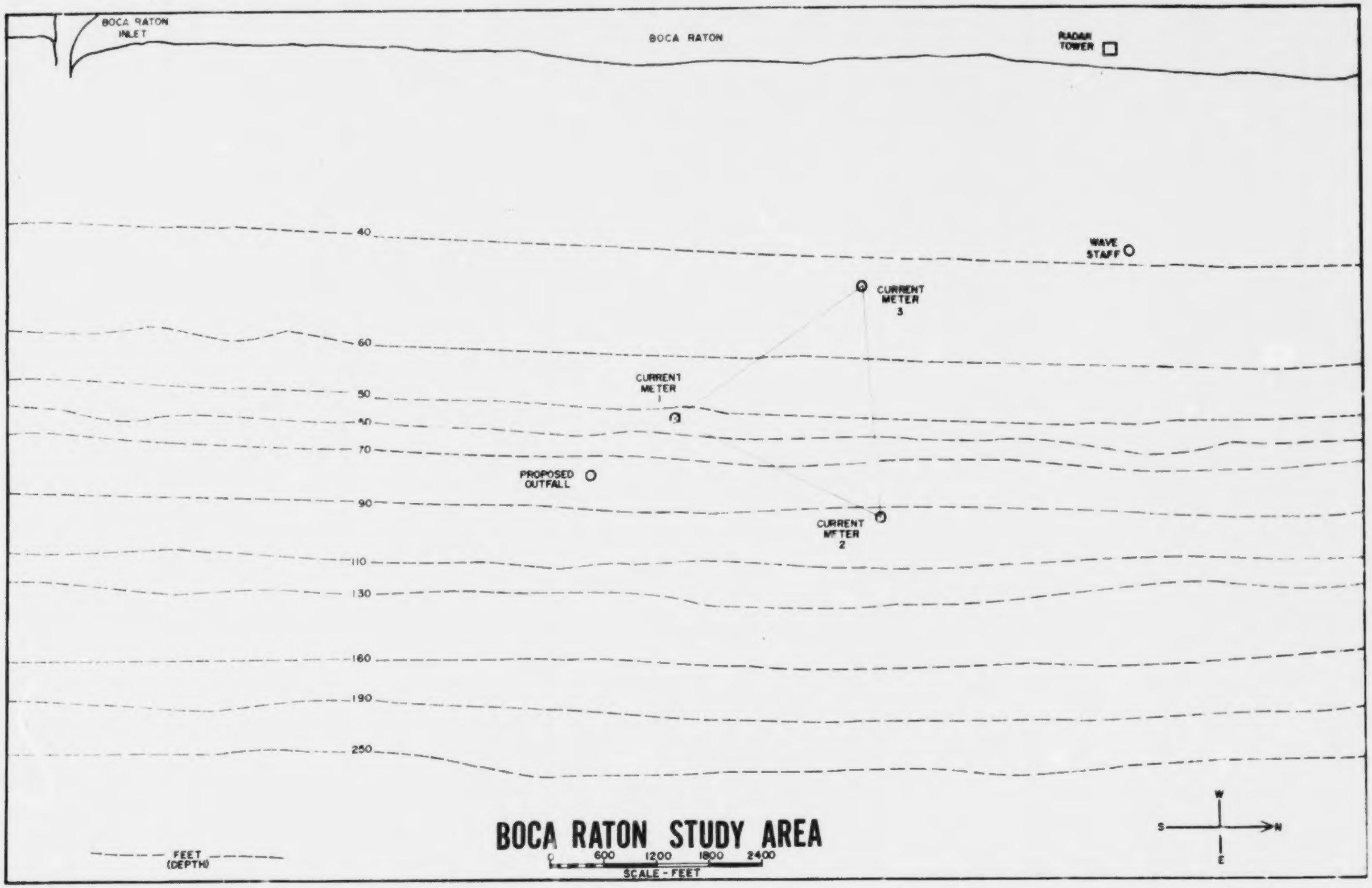
The observed coastal water movements are the resultants of the combined tide, wind and Florida Current induced currents. In order to separate the forces and their resulting currents it is necessary to record the significant parameters involved, simultaneously and continuously over long time periods. To accomplish this, a sensor array was constructed off Boca Raton to record current speed and direction, temperature profile, wave height, tidal fluctuations of sea level, and wind speed and direction.

A triangular array of Marine Advisor Savonius Rotor current meters (Model #Q-12) was constructed across the shelf at Boca Raton (Figure 23). Each current meter was rigidly mounted 25 feet beneath the surface on top of a stationary tower which was cemented and guyed into the bottom, thus eliminating any error due to instrument motion. The current meters were separated by a distance of 2640 feet. Current meter #2 was positioned at the edge of the Continental Shelf. Three Yellow Springs Instrument Company thermistor probes were attached to the support tower of current meter #2 at depths of 25, 55, and 95 feet. Wave heights and mean sea level fluctuations were measured with a wave staff constructed by the Georgia Institute of Technology Field Station under a Navy Contract. Wind speed and direction was measured 30 feet above the beach with an anemometer on loan from Florida State University. The signals from the above sensors were transmitted via cable back to Georgia Tech. Field Station and Radar Tower for analog recording.

A fourth Marine Advisors Current Meter was rigidly constructed near the Pompano Outfall 25 feet beneath the surface (Figure 24).

Horizontal and vertical distributions of temperature and salinity were measured with a portable, in-situ, Beckman RS-5 Salinometer. Spacial distributions of currents across the shelf were measured with free drifting current crosses. Accurate positioning was obtained by using shore located optical transits.

The current meters were calibrated in the laboratory electronically and in the field by comparing data readout against dye measurements. Divers released dye at the current meters and timed the dye displacement over a known distance. This procedure was repeated five times at each meter. The difference in speed between the average of the five dye releases and the average


BOCA RATON INLET
BOCA RATON
RADAR TOWER
40
WAVE STAFF
CURRENT METER 3
60
CURRENT METER 1
50
50
70
PROPOSED OUTFALL
90
CURRENT METER 2
110
130
160
190
250
W
S
N
E
FEET (DEPTH)
0
600
1200
1800
2400
SCALE - FEET

BOCA RATON STUDY AREA

FIG. 23

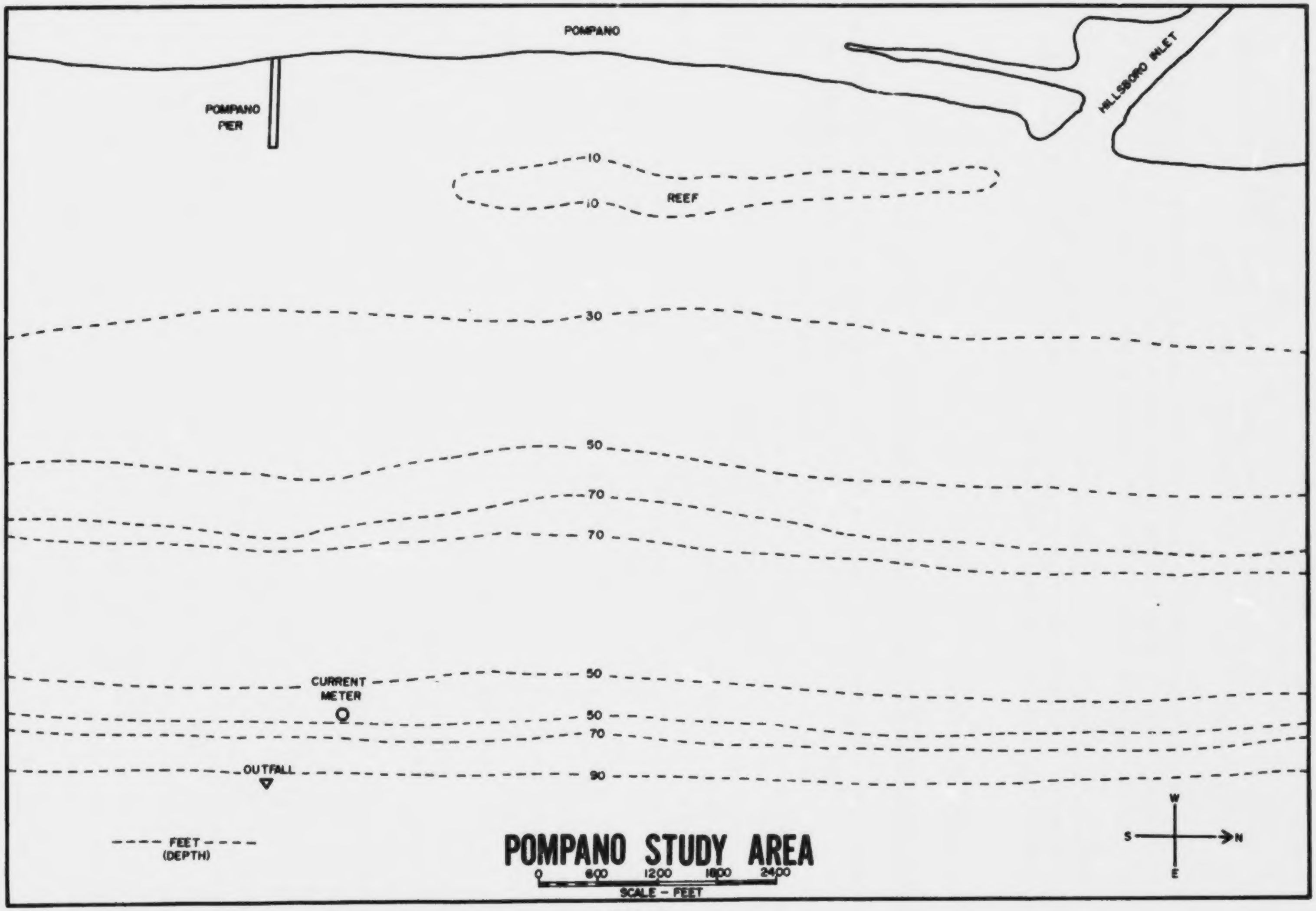

POMPANO
POMPANO PIER
HILLSBORO INLET
10
10
REEF
30
50
70
70
50
CURRENT METER
50
70
OUTFALL
90
FEET (DEPTH)
POMPANO STUDY AREA
0 600 1200 1800 2400
SCALE - FEET
W
S
N
E

FIG. 24

of the current meter data was never greater than .04 knots. Because of the rapid biological fouling in these shallow, nearshore waters the current meter had to be checked frequently and replaced after four to six weeks of operation.

The thermistors were calibrated in the lab by comparing them to a Hg. thermometer. The thermistors were found to be linear and interchangeable over the desired temperature range (67.5-92.5°F).

The Beckman portable salinometer was calibrated with the aid of a laboratory, inductive cell type salinometer on loan from the ESSA Physical Oceanographic Lab in Miami.

METHOD AND PROCEDURE

TEMPERATURE-SALINITY-CURRENT OBSERVATIONS

Transects of temperature and salinity perpendicular to the shore across the Continental Shelf at Pompano and Boca Raton have been conducted since December 5, 1968. Each transect consisted of a line of stations starting inshore and proceeded east until the Florida Current was reached. This was determined when the temperature and salinity became horizontally stable and of the order of magnitude expected of the Florida Current. Other visual indications of the Florida Current were boat drift (as determined from shore located transists) and the deep blue water color typical of the Florida Current. At each station temperature and salinity were measured at ten foot intervals from the surface to the bottom or to a depth of 240 feet which was the cable limit. Stations were usually less than 3000 feet apart. Free drifting current crosses were released in the surface, 20 and 40 foot depths at intervals along the transects. Current crosses were made of plywood sheets (1½' x 1½'), and were either weighted to suspend from a surface float at a desired depth or were balanced to remain a few inches below the surface with only a small marker pole above surface. Figures 25 through 45 are typical examples of transects for different seasons at Pompano. Pompano outfall discharges at a point where the bottom profile intersects the 90 foot water depth.

The temperature transects show a seasonal variation of sea surface temperature of approximately 16°F. A minimum temperature of around 70°F occurs in January and February and increases to a maximum of about 86°F in June and July. The vertical temperature structure of the nearshore waters is well mixed with small vertical temperature gradients from mid-August to the latter part of April. Strong stratification with vertical temperature gradients as high as 12°F in 90 feet of water begin to appear at this time and predominate until mid-August. Large vertical temperature gradients produce large density (sigma-t) gradients and thus a very stable water column. This is shown in the waste disposal section of this report to be very important

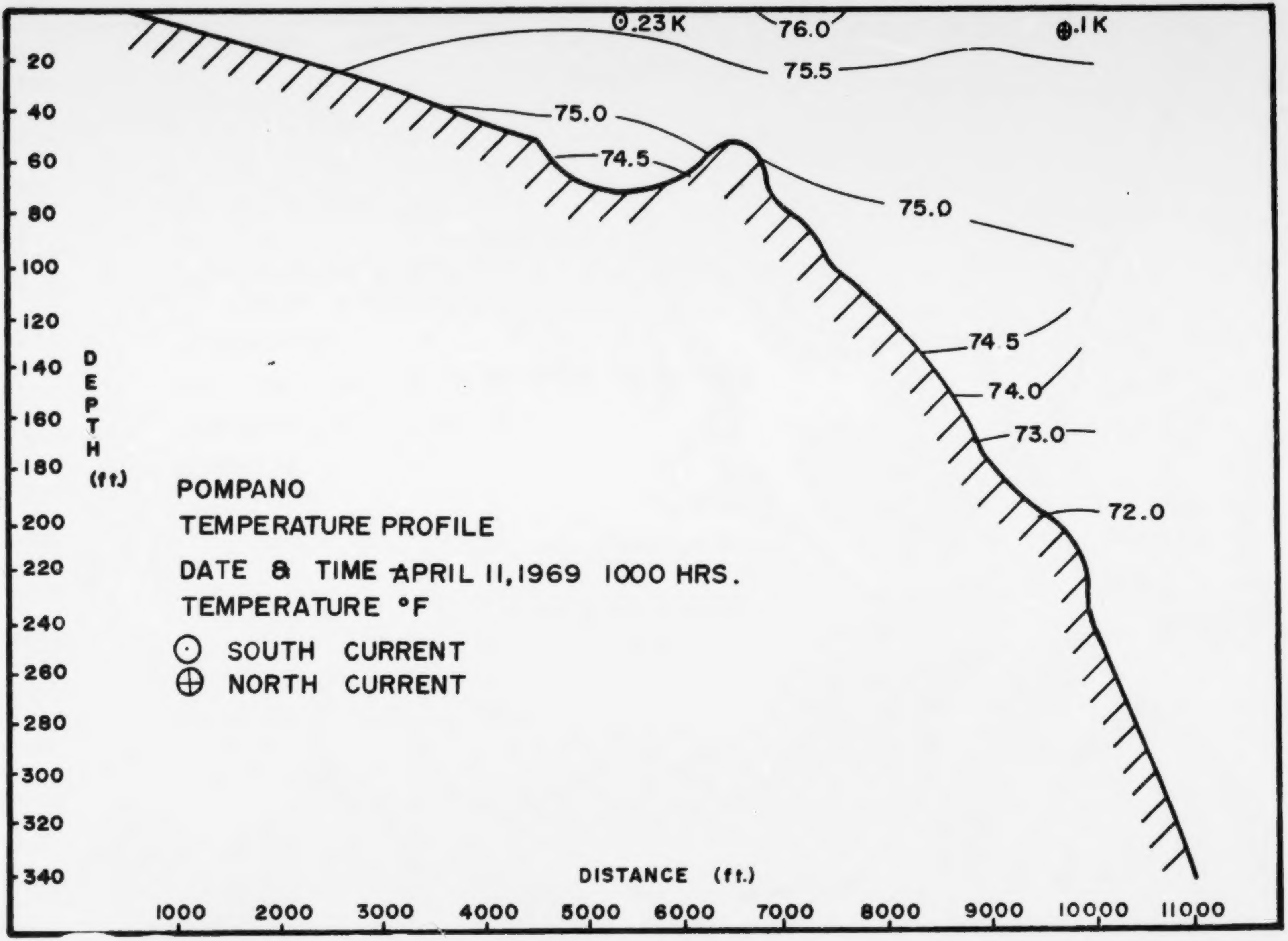

⊙.23 K
76.0
⊕.1 K
75.5
75.0
74.5
75.0
74.5
74.0
73.0
72.0
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
POMPANO
TEMPERATURE PROFILE
DATE & TIME APRIL 11, 1969 1000 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 25

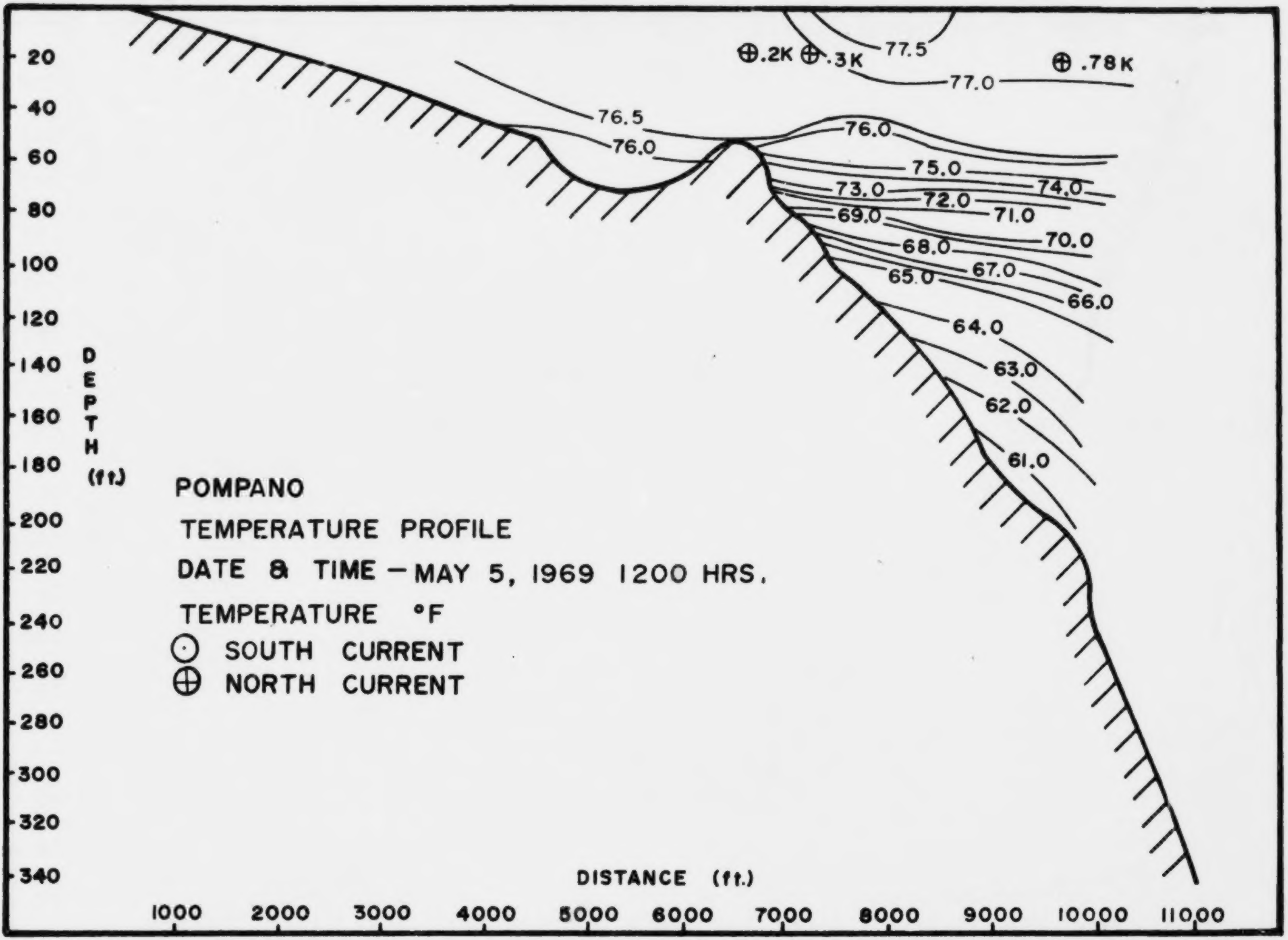

POMPANO
TEMPERATURE PROFILE
DATE & TIME — MAY 5, 1969 1200 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
⊕ .2K
⊕ .3K
⊕ .78K
77.5
77.0
76.5
76.0
76.0
76.0
75.0
74.0
73.0
72.0
71.0
70.0
69.0
68.0
67.0
66.0
65.0
64.0
63.0
62.0
61.0

Fig. 26

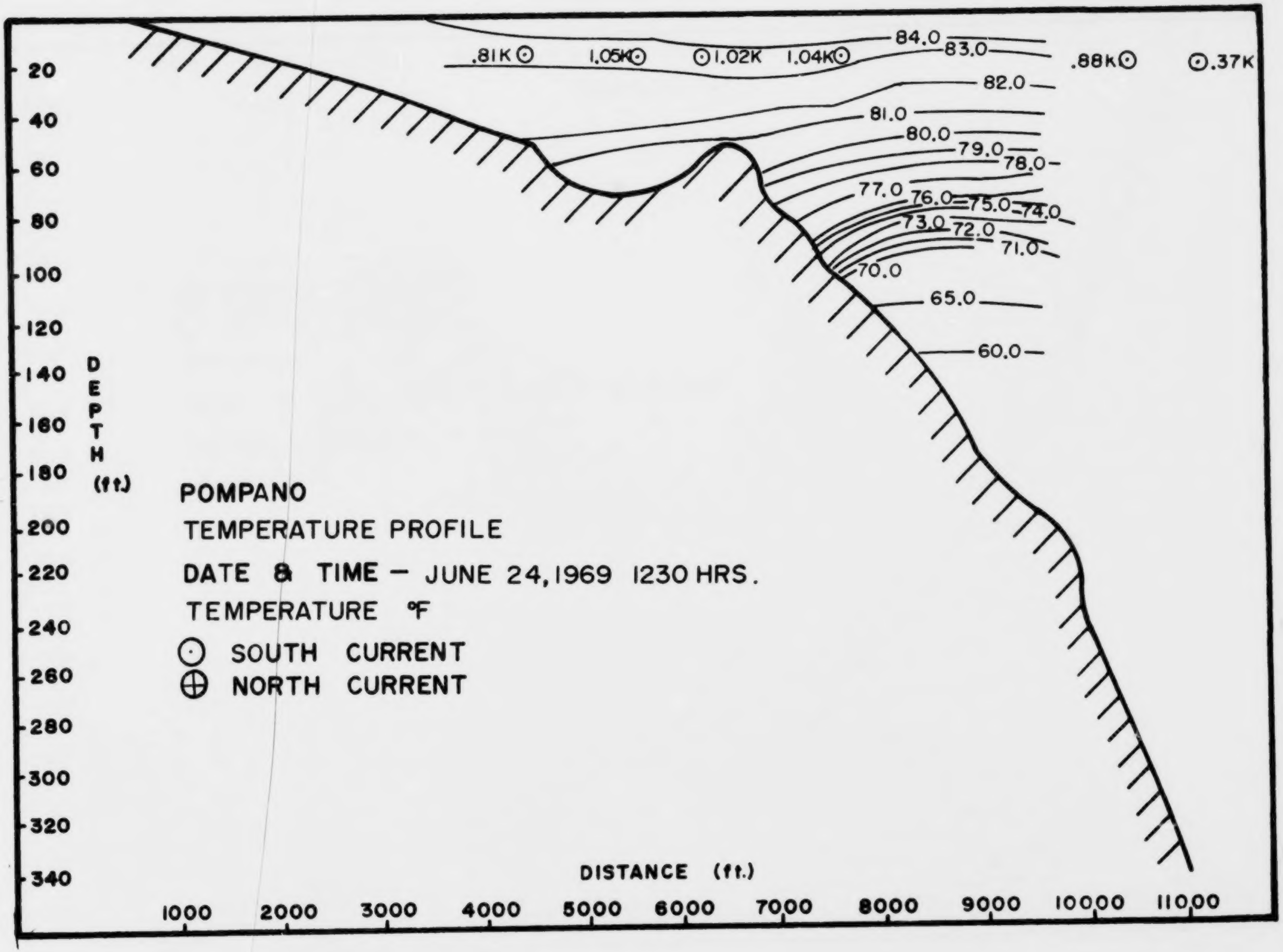

POMPANO
TEMPERATURE PROFILE
DATE & TIME – JUNE 24, 1969 1230 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
.81K⊙
1.05K⊙
⊙1.02K
1.04K⊙
.88K⊙
⊙.37K
84.0
83.0
82.0
81.0
80.0
79.0
78.0
77.0
76.0
75.0
74.0
73.0
72.0
71.0
70.0
65.0
60.0
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 27

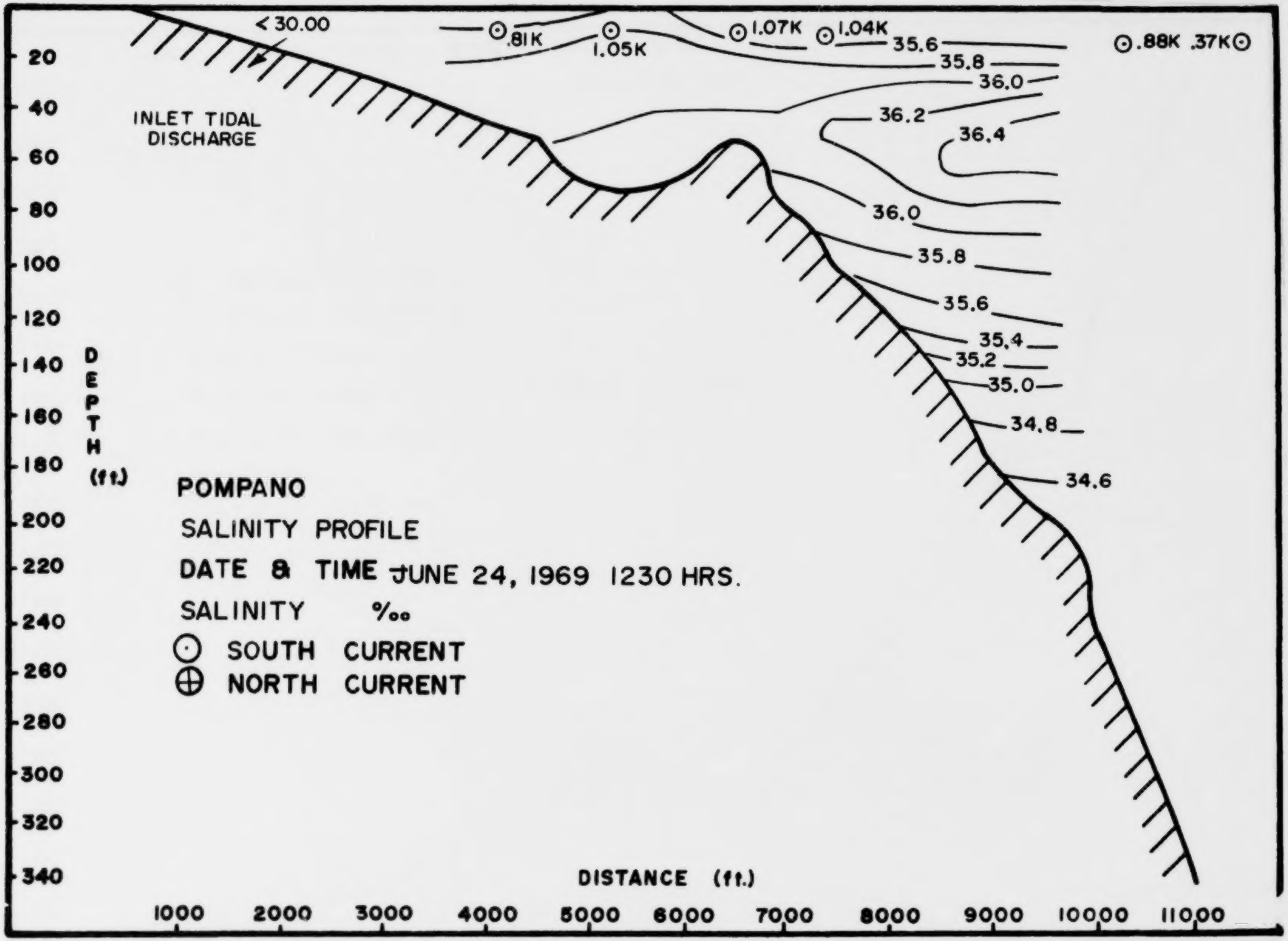

POMPANO
SALINITY PROFILE
DATE & TIME JUNE 24, 1969 1230 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
INLET TIDAL DISCHARGE
< 30.00
⊙ .81K
⊙ 1.05K
⊙ 1.07K
⊙ 1.04K
⊙ .88K
.37K ⊙
35.6
35.8
36.0
36.2
36.4
36.0
35.8
35.6
35.4
35.2
35.0
34.8
34.6
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 28

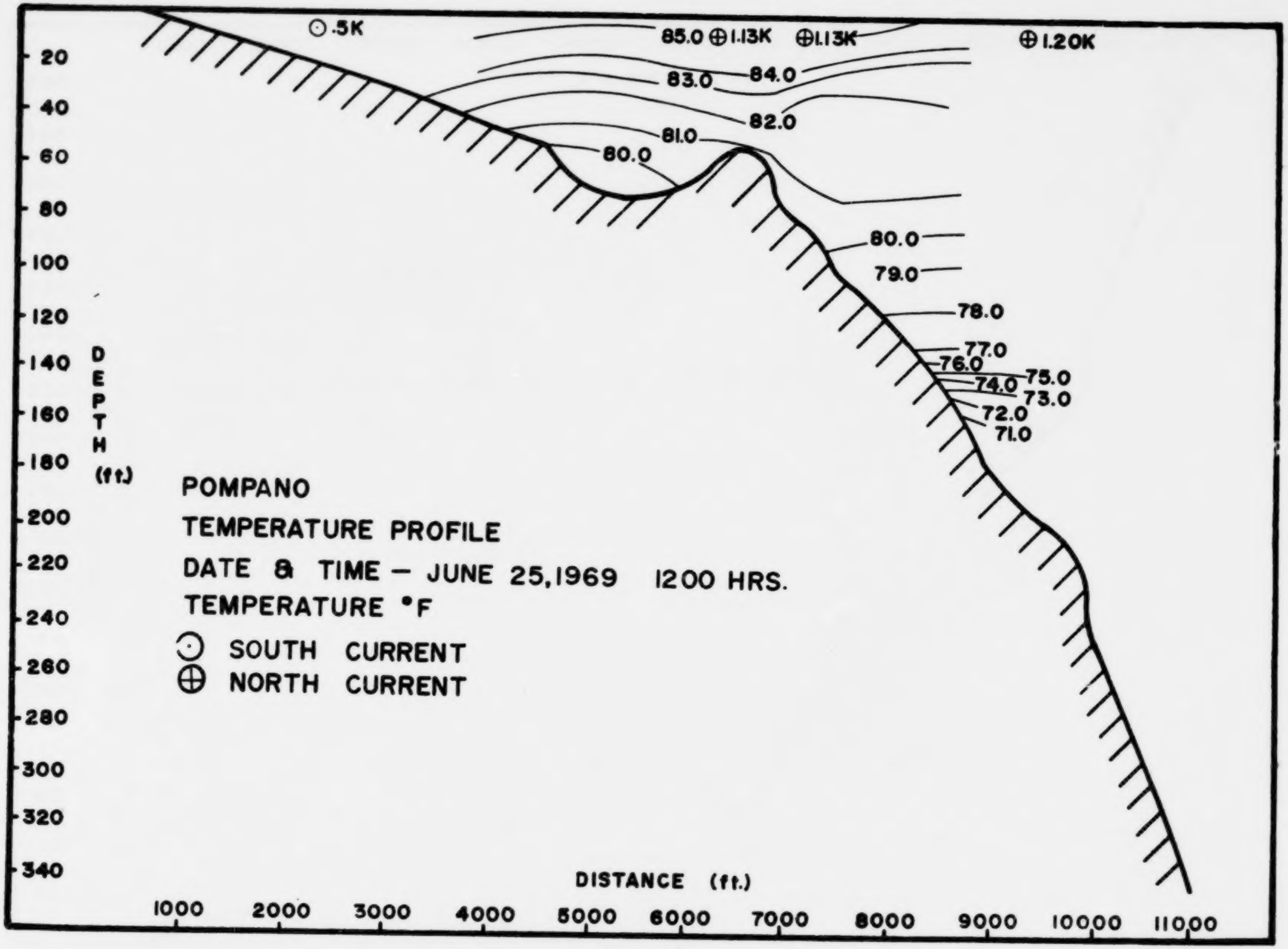

⊙ .5K
85.0 ⊕ 1.13K
⊕ 1.13K
⊕ 1.20K
84.0
83.0
82.0
81.0
80.0
80.0
79.0
78.0
77.0
76.0
75.0
74.0
73.0
72.0
71.0
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
POMPANO
TEMPERATURE PROFILE
DATE & TIME — JUNE 25,1969 1200 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 29

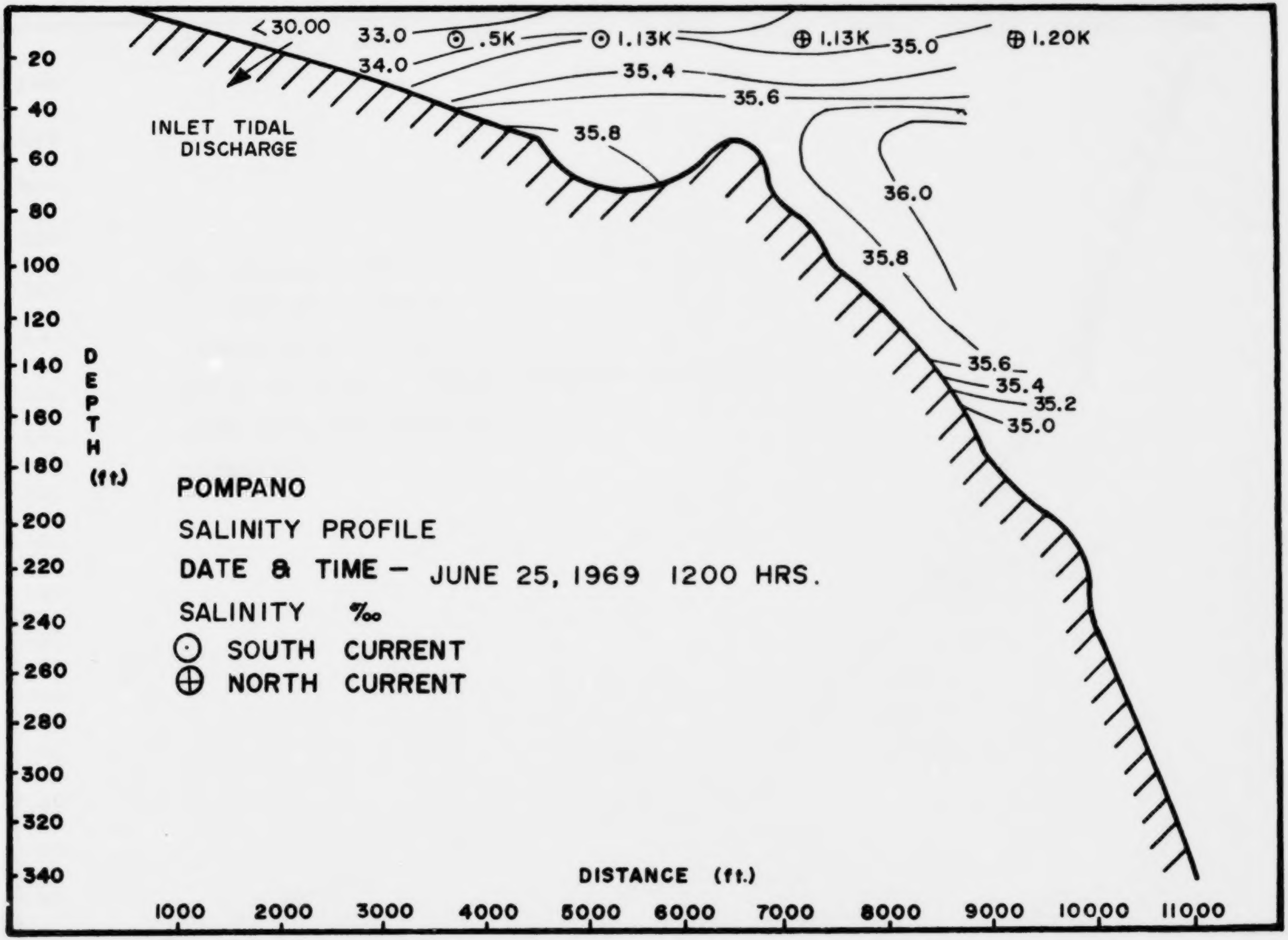

POMPANO
SALINITY PROFILE
DATE & TIME – JUNE 25, 1969 1200 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
INLET TIDAL DISCHARGE
<30.00
33.0
34.0
⊙ .5K
⊙ 1.13K
⊕ 1.13K
⊕ 1.20K
35.0
35.4
35.6
35.8
36.0
35.8
35.6
35.4
35.2
35.0
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 30

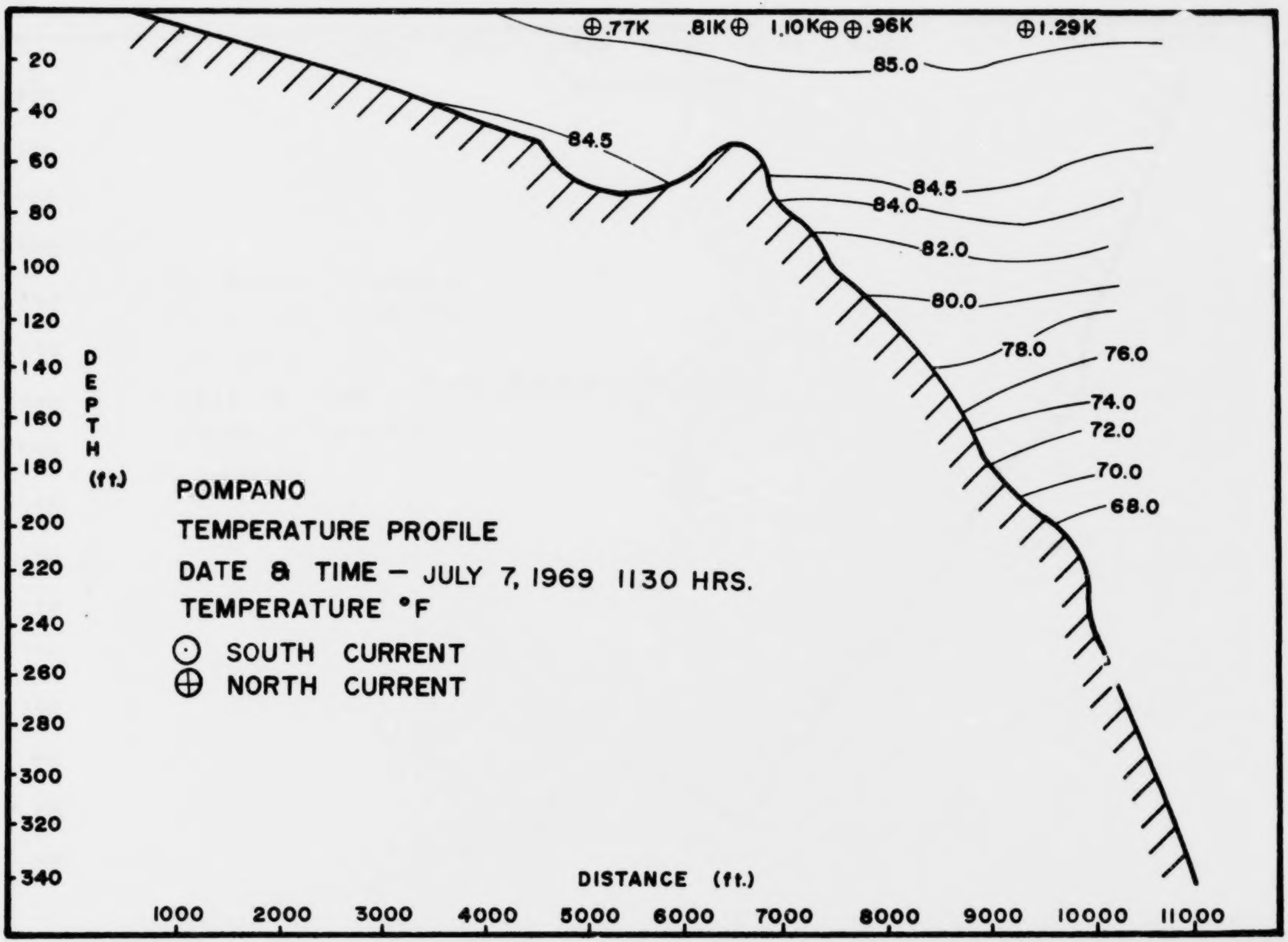

⊕.77K
.81K⊕
1.10K⊕
⊕.96K
⊕1.29K
85.0
84.5
84.5
84.0
82.0
80.0
78.0
76.0
74.0
72.0
70.0
68.0
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
POMPANO
TEMPERATURE PROFILE
DATE & TIME — JULY 7, 1969 1130 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
100,00
110,00

Fig. 31

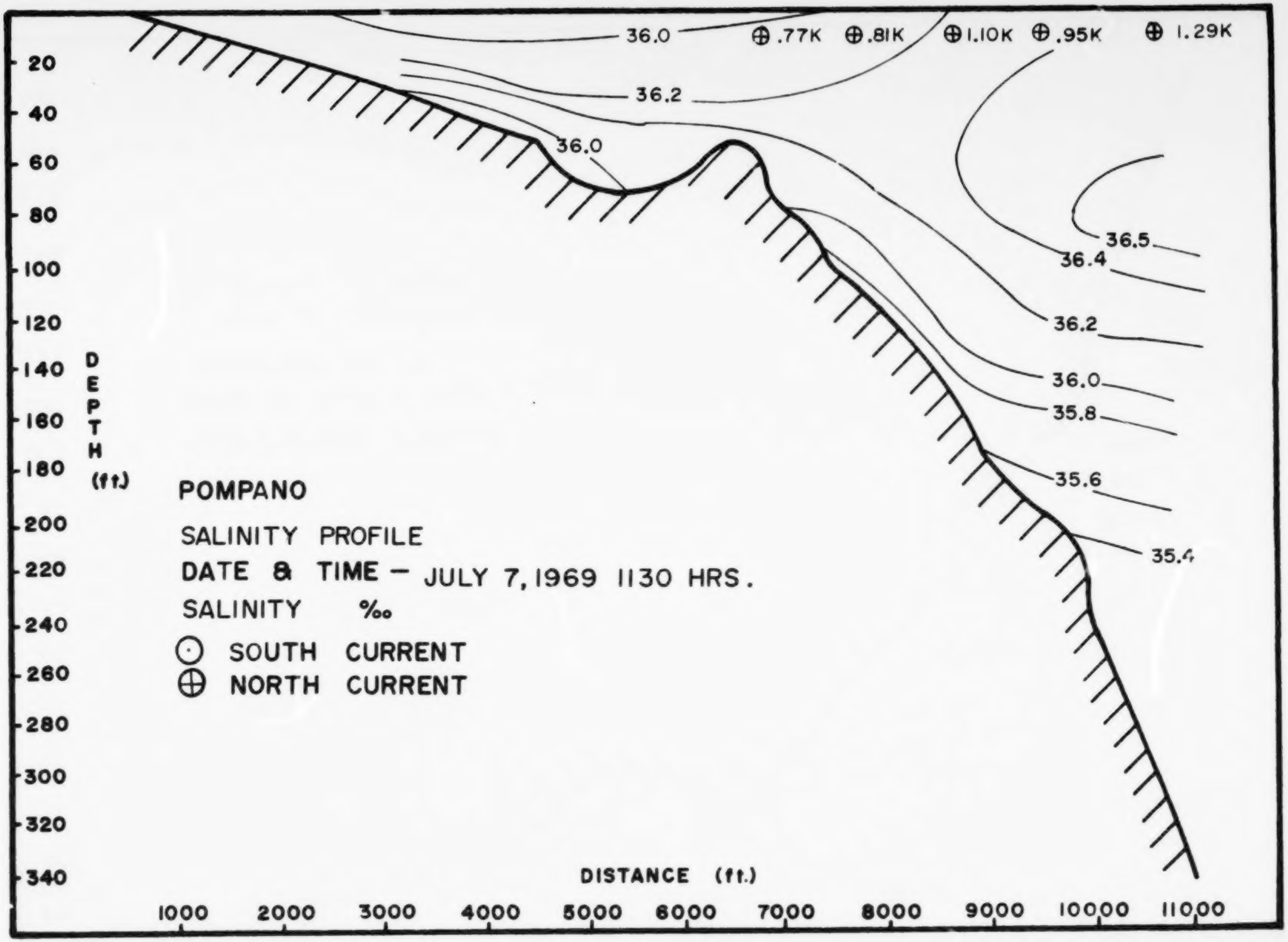

36.0
⊕ .77K
⊕ .81K
⊕ 1.10K
⊕ .95K
⊕ 1.29K
36.2
36.0
36.5
36.4
36.2
36.0
35.8
35.6
35.4
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DEPTH (ft.)
POMPANO
SALINITY PROFILE
DATE & TIME — JULY 7, 1969 1130 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 32

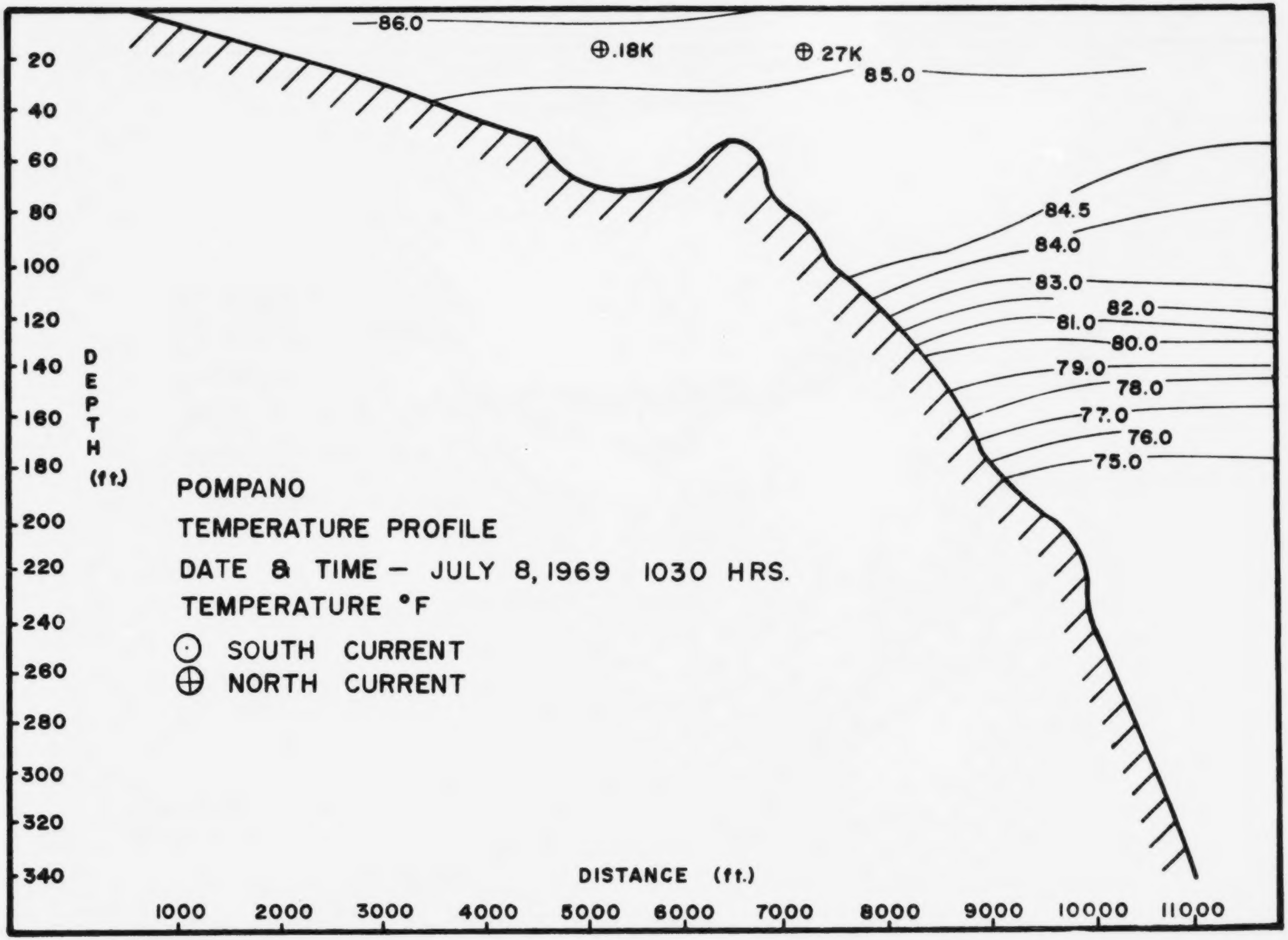

-86.0
⊕ .18K
⊕ 27K
85.0
84.5
84.0
83.0
82.0
81.0
80.0
79.0
78.0
77.0
76.0
75.0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DEPTH (ft.)
POMPANO
TEMPERATURE PROFILE
DATE & TIME — JULY 8, 1969 1030 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 33

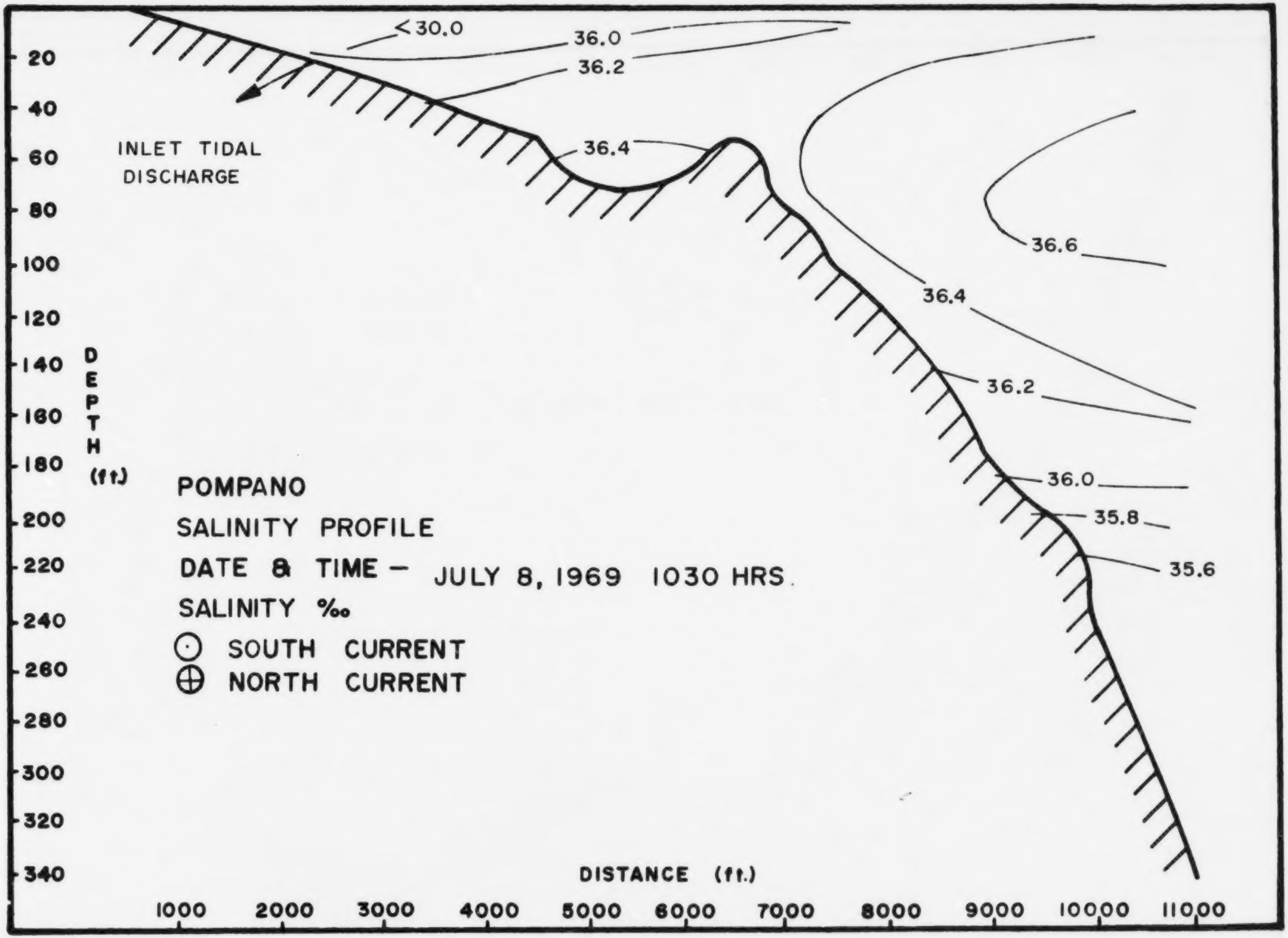

POMPANO
SALINITY PROFILE
DATE & TIME — JULY 8, 1969 1030 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
INLET TIDAL DISCHARGE
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
<30.0
36.0
36.2
36.4
36.6
36.4
36.2
36.0
35.8
35.6

Fig. 34

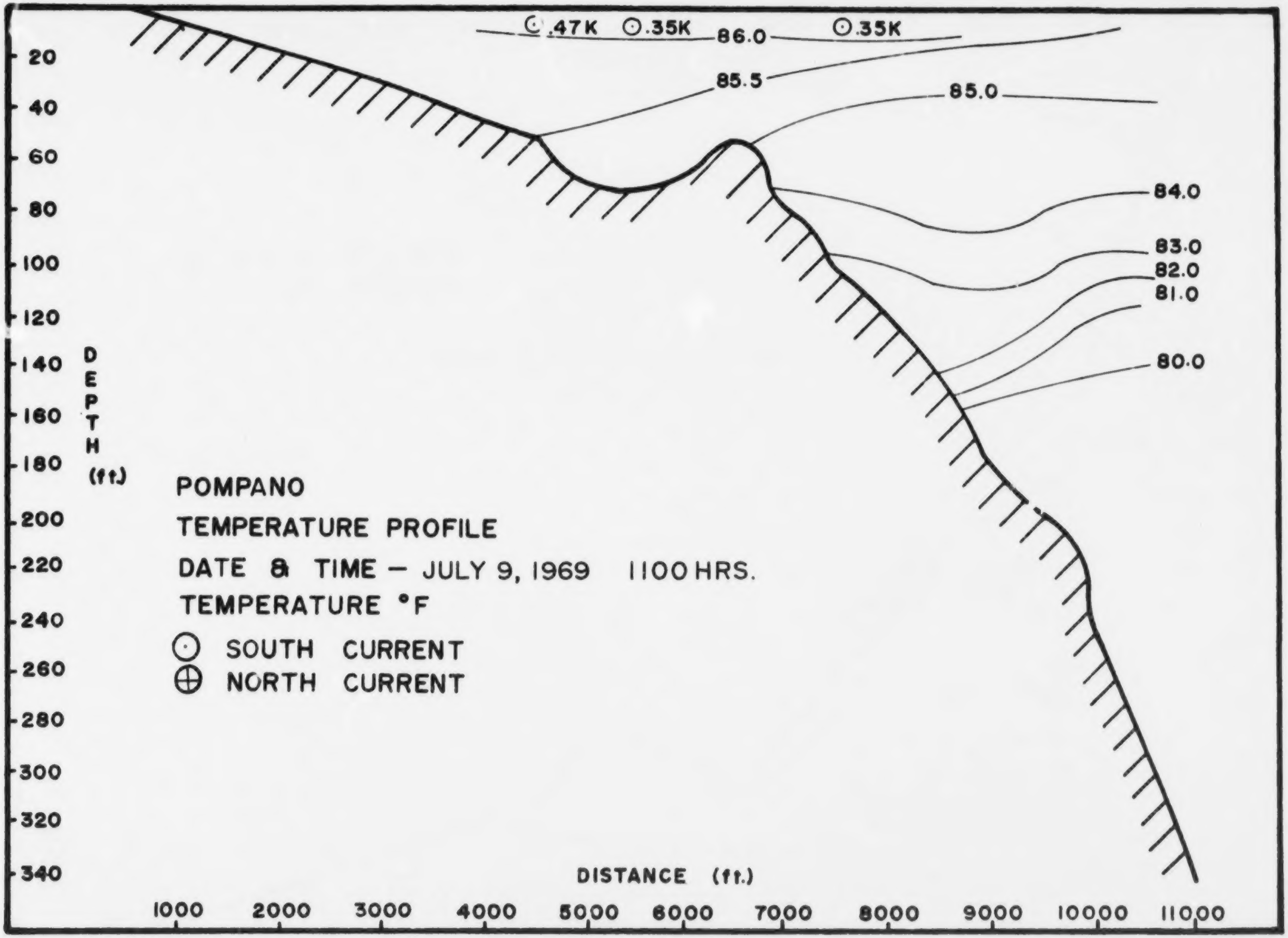

⊙ .47K
⊙ .35K
86.0
⊙ .35K
85.5
85.0
84.0
83.0
82.0
81.0
80.0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DEPTH (ft.)
POMPANO
TEMPERATURE PROFILE
DATE & TIME — JULY 9, 1969 1100 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 35

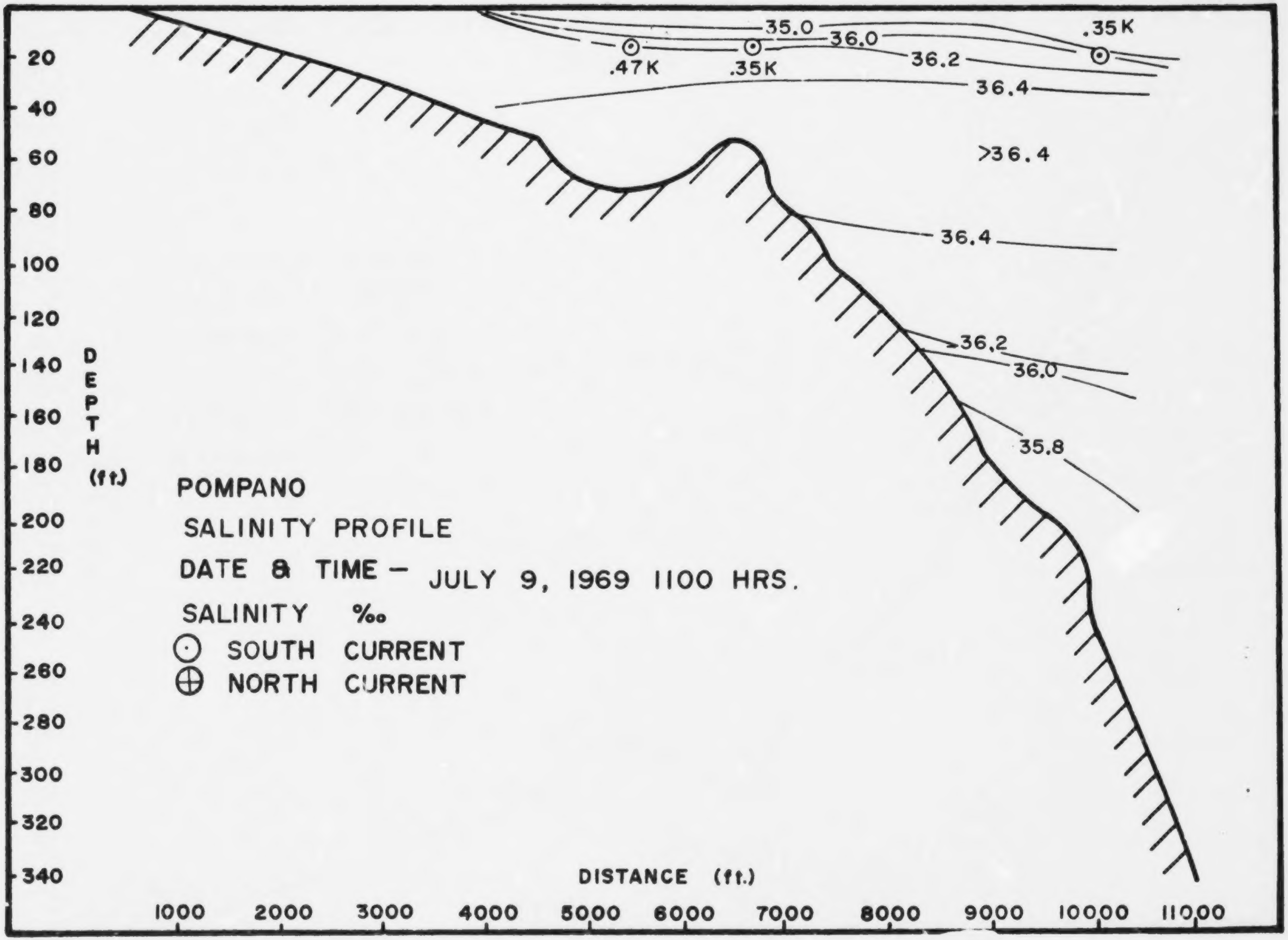

35.0
36.0
36.2
36.4
.47K
.35K
.35K
>36.4
36.4
36.2
36.0
35.8
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
POMPANO
SALINITY PROFILE
DATE & TIME – JULY 9, 1969 1100 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 36

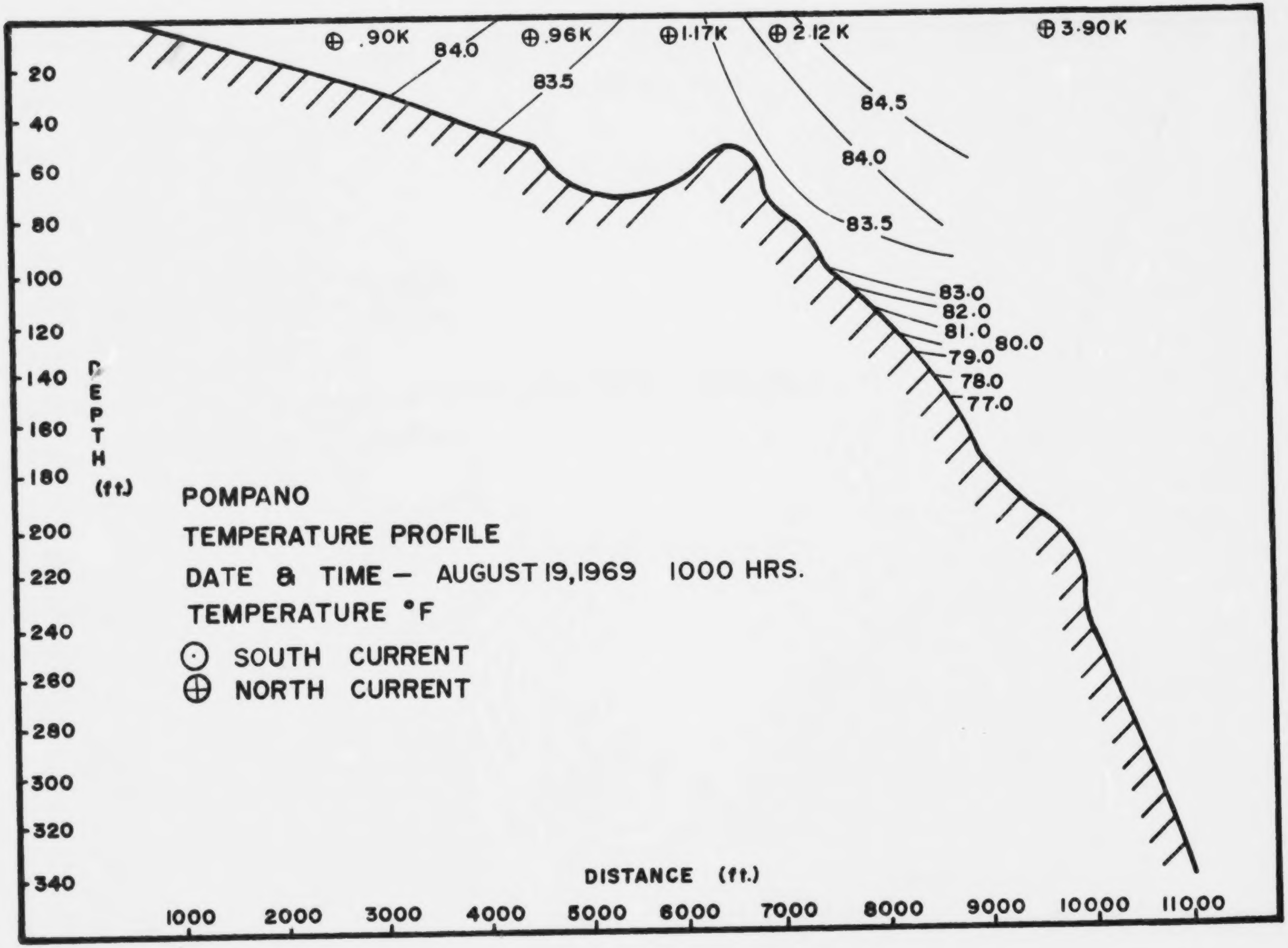

⊕ .90K
⊕ .96K
⊕ 1.17K
⊕ 2.12 K
⊕ 3.90K
84.0
83.5
84.5
84.0
83.5
83.0
82.0
81.0
80.0
79.0
78.0
77.0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DEPTH (ft.)
POMPANO
TEMPERATURE PROFILE
DATE & TIME — AUGUST 19,1969 1000 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 37

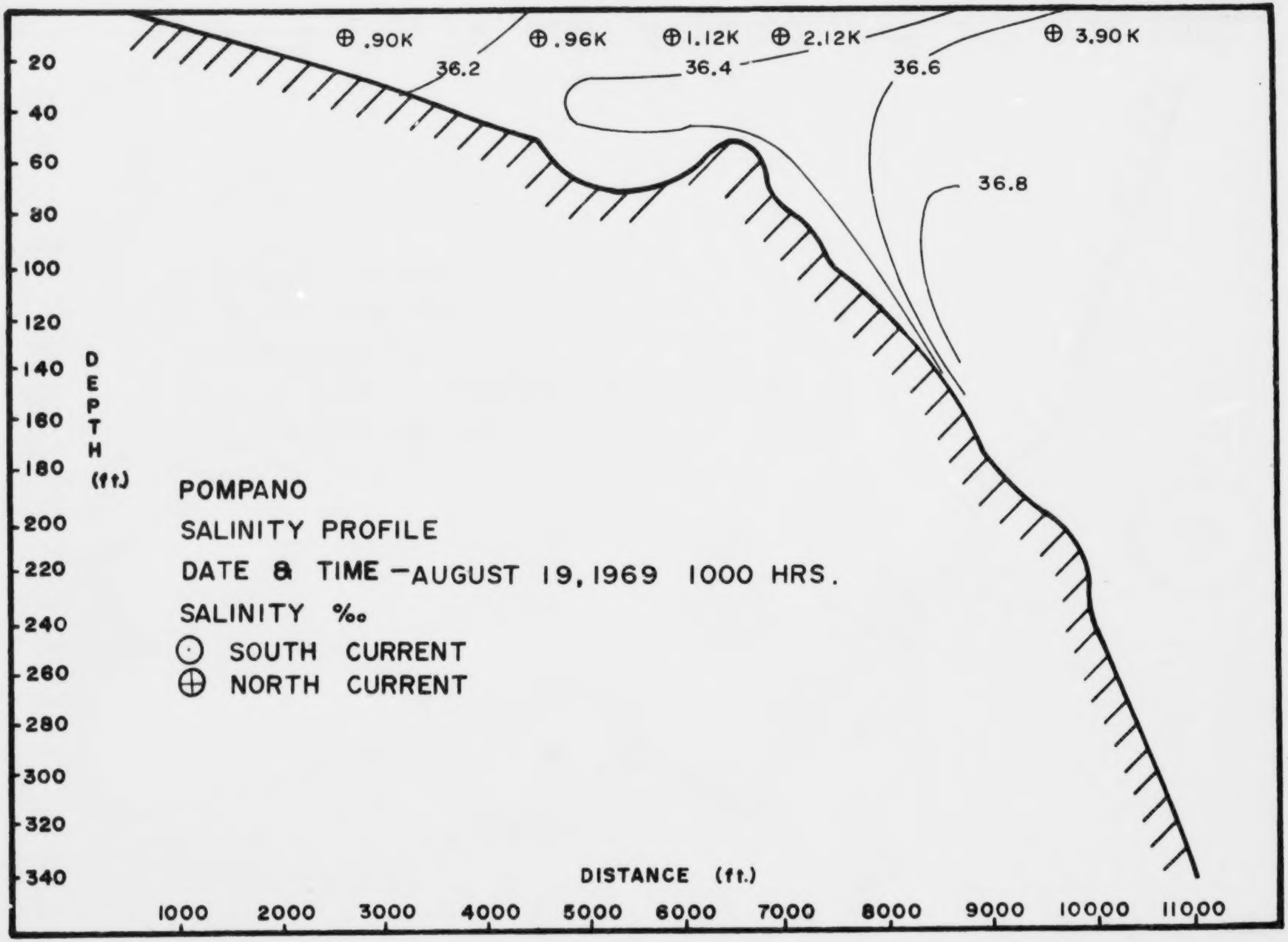

⊕ .90K
⊕ .96K
⊕ 1.12K
⊕ 2.12K
⊕ 3.90K
36.2
36.4
36.6
36.8
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DEPTH (ft.)
POMPANO
SALINITY PROFILE
DATE & TIME – AUGUST 19, 1969 1000 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 38

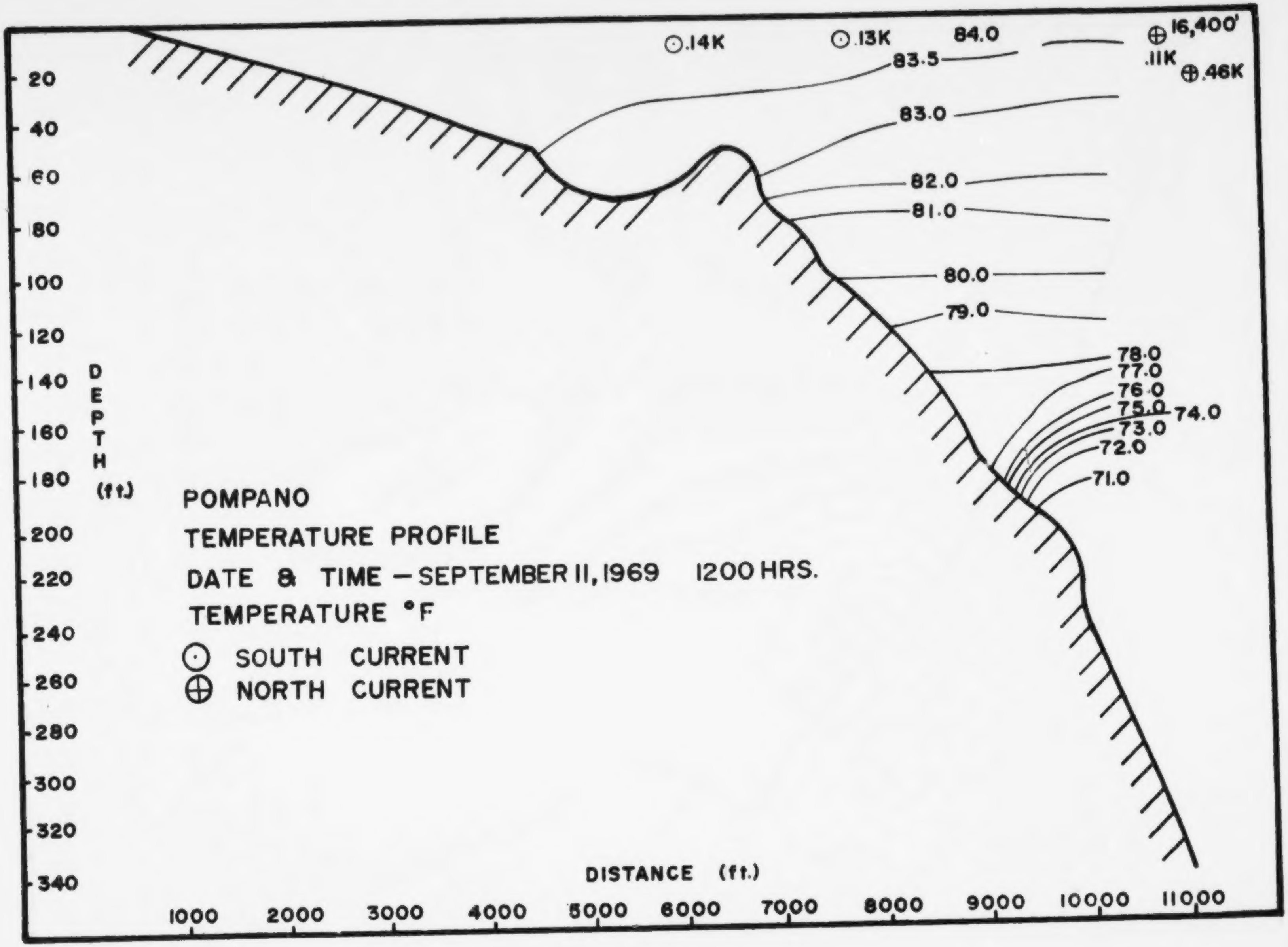

POMPANO
TEMPERATURE PROFILE
DATE & TIME – SEPTEMBER 11, 1969 1200 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
⊙.14K
⊙.13K
84.0
⊕16,400'
.11K
⊕.46K
83.5
83.0
82.0
81.0
80.0
79.0
78.0
77.0
76.0
75.0
74.0
73.0
72.0
71.0
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 39

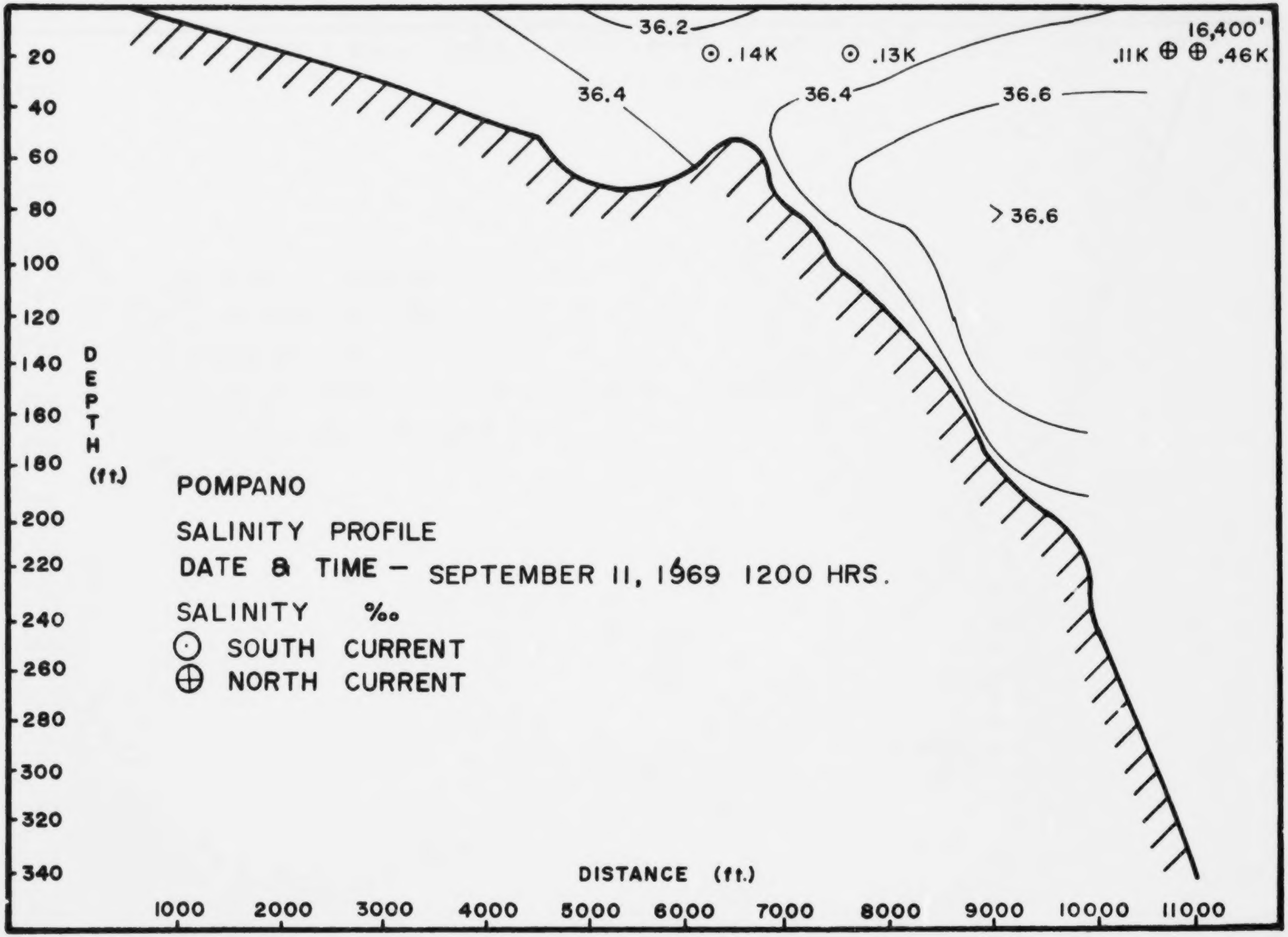

POMPANO
SALINITY PROFILE
DATE & TIME – SEPTEMBER 11, 1969 1200 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
36.2
36.4
36.4
36.6
> 36.6
⊙ .14K
⊙ .13K
.11K ⊕
⊕ .46K
16,400'

Fig. 40

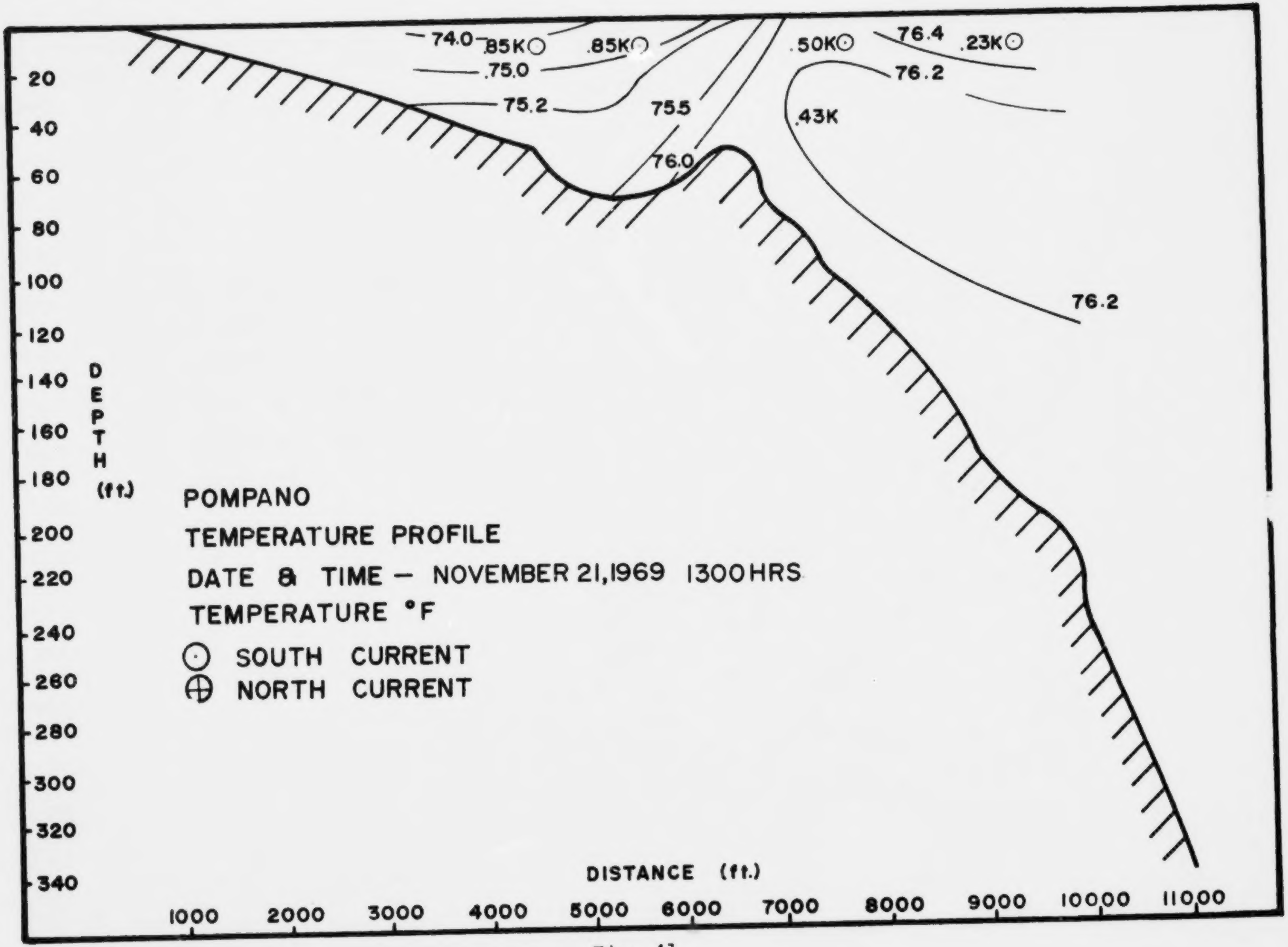
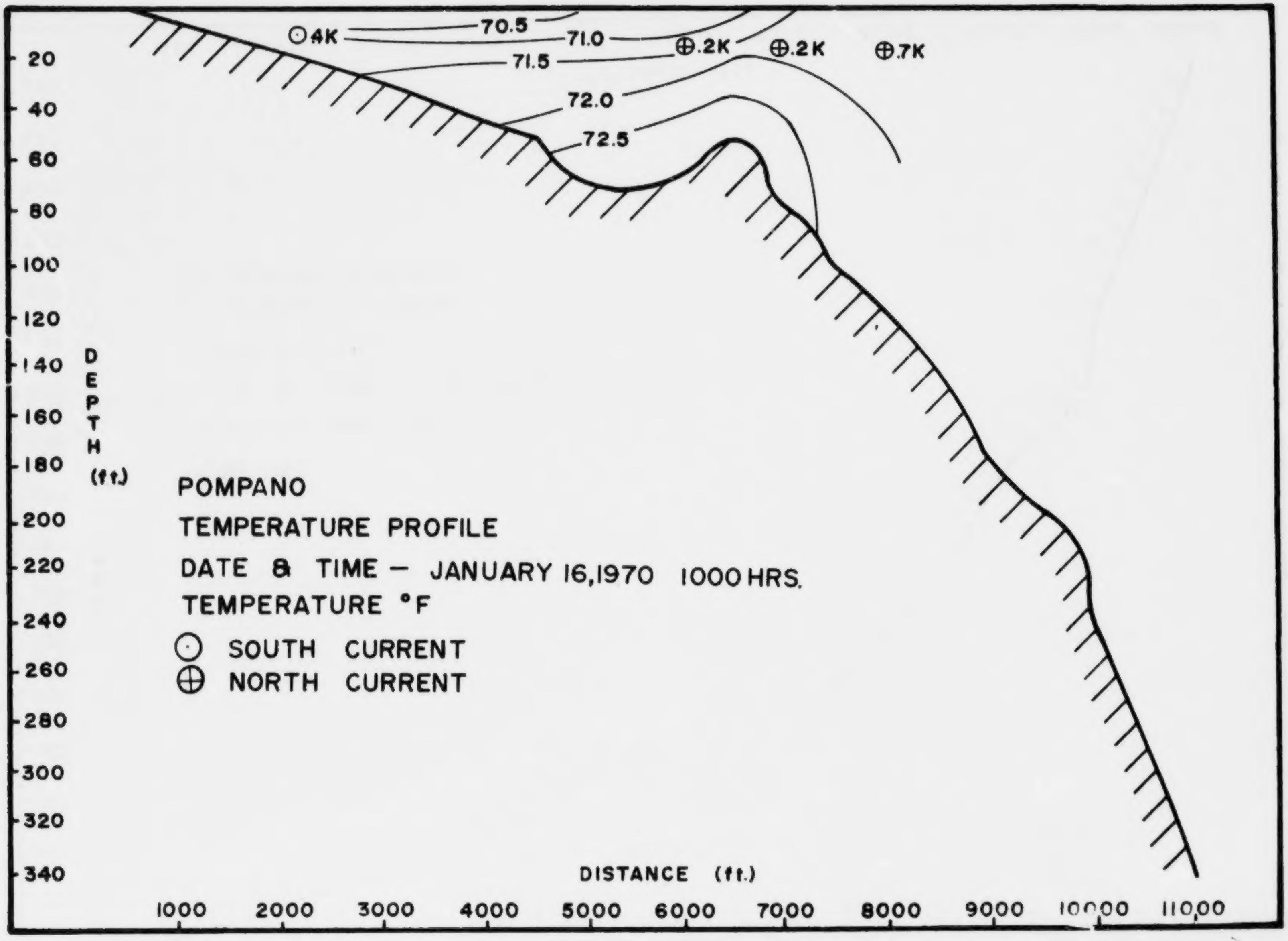

74.0
.85K⊙
.85K⊙
.50K⊙
76.4
.23K⊙
.75.0
76.2
75.2
75.5
.43K
76.0
76.2
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DEPTH (ft.)
POMPANO
TEMPERATURE PROFILE
DATE & TIME — NOVEMBER 21,1969 1300HRS
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 41



POMPANO
TEMPERATURE PROFILE
DATE & TIME – JANUARY 16,1970 1000 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
⊙4K
⊕.2K
⊕.2K
⊕.7K
70.5
71.0
71.5
72.0
72.5
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 42

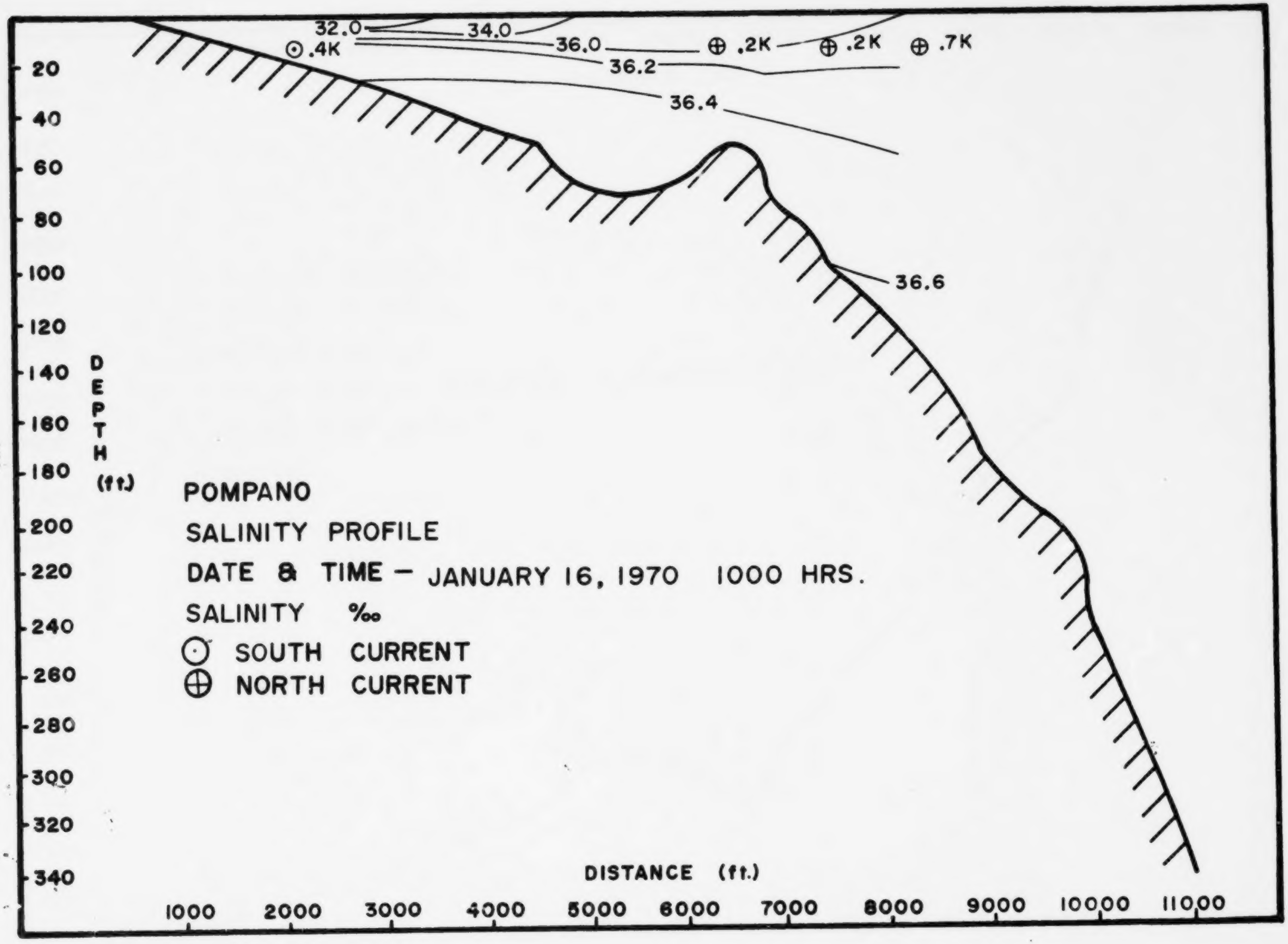

32.0
34.0
36.0
36.2
36.4
36.6
⊙ .4K
⊕ .2K
⊕ .2K
⊕ .7K
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DEPTH (ft.)
POMPANO
SALINITY PROFILE
DATE & TIME – JANUARY 16, 1970 1000 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 43

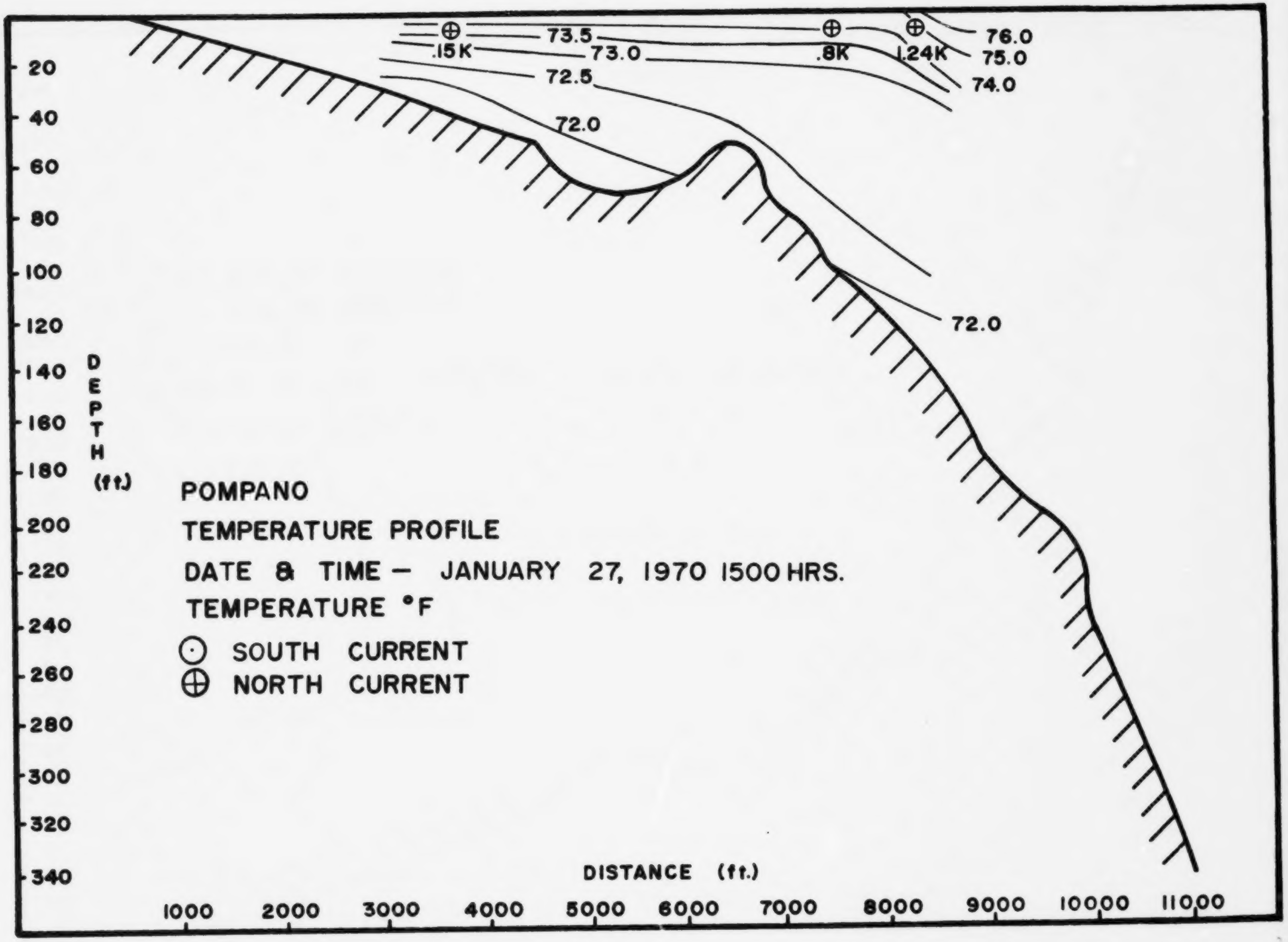

POMPANO
TEMPERATURE PROFILE
DATE & TIME — JANUARY 27, 1970 1500 HRS.
TEMPERATURE °F
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
76.0
75.0
74.0
73.5
73.0
72.5
72.0
72.0
.15K
.8K
1.24K

Fig. 44

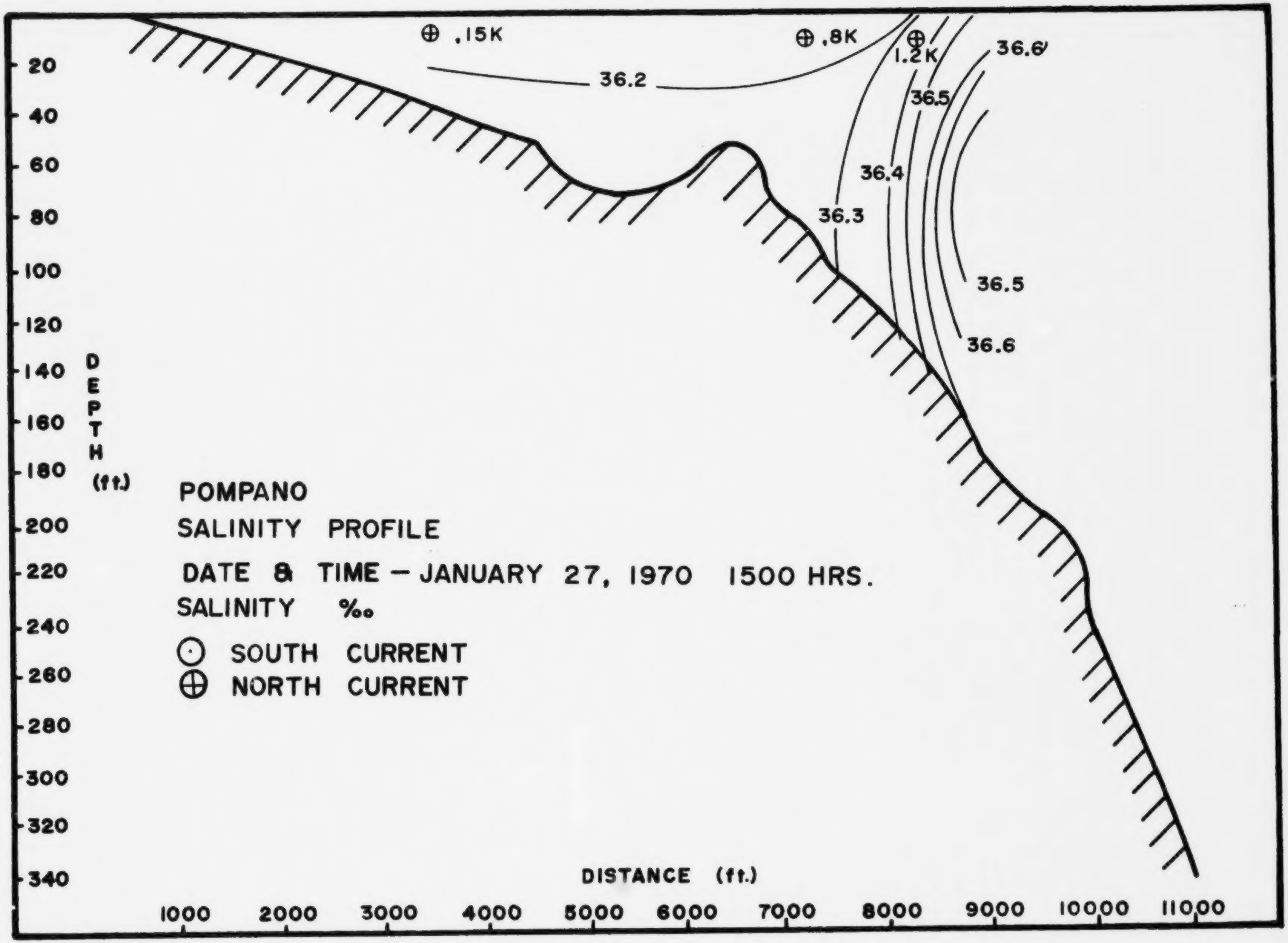

POMPANO
SALINITY PROFILE
DATE & TIME — JANUARY 27, 1970 1500 HRS.
SALINITY ‰
⊙ SOUTH CURRENT
⊕ NORTH CURRENT
⊕ .15K
⊕ .8K
⊕ 1.2K
36.2
36.3
36.4
36.5
36.6
36.5
36.6
DEPTH (ft.)
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
DISTANCE (ft.)
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000

Fig. 45

in mixing the discharged effluent at a subsurface depth and preventing the waste material from surfacing.

Temperature isotherms across the Continental Shelf show a seasonal variation. In the fall, winter and spring, north currents show a deepening of isotherms in the seaward direction. The western edge of the Florida Current is seen to coincide with the "cold wall" of sharply sloping isotherms. Pronounced horizontal temperature gradients in the surface will also position the western edge. Measurements of current speed and temperature indicate that the western edge of the Florida Current is meandering laterally from its westward most position on the shelf to about 4.7 miles offshore which is in good agreement with the meandering fluctuations found by Schmitz and Richardson (1968). During the late spring and early summer, strong stratification predominates and isotherms tend to become horizontal, making positioning of the western edge of the Florida Current with temperature measurements difficult.

Of major importance to nearshore circulation is the frequent occurance of current reversals. These reversals are thought to be produced by cyclonic eddies which spin off the Florida Current due to the frictional interaction with the side boundary and are advected northward through the shelf waters. These eddies produce south currents in the shelf waters of equal magnitude as the north currents. In general the south currents will be strongest, and the distance offshore to the north currents will be greatest, when the center of the eddy is directly offshore. During the passage of an eddy, water from the Florida Current is advected shoreward then turns south, therefore, temperature isotherms become horizontal and at times show a slope deepening toward the west with south currents.

The salinity transects consistently show a subsurface core of high salinity water. The salinity in the core ranges from 36.2 to 36.6 0/00 and represents the high salinity core of the Florida Current. Transects with northward coastal currents show the core of the 36.4 0/00 isohaline to vary horizontally from 4500 to 8500 feet offshore and vertically, the core ranges from 30 to 60 feet beneath the surface. The position changes of the high salinity core reflect the latteral meandering of the western boundary of the Florida Current. The western boundary is seen to be located over the Continental Slope (8000 - 9000 feet offshore at Pompano) with an oscillation about this position on the order of one mile either east or west for north currents. The distance offshore to the Florida Current is thus dependent upon the width of the Continental Shelf as defined by the slope of the bottom profile. The distance offshore to strong north currents is extended up to five miles during the passage of an eddy. Transects with south currents consistently show higher salinity water closer to shore. This is because a south current represents a Florida Current eddy with water being shed directly off the Florida Current traveling west and then turning south. At the end of an eddy the currents shift counterclockwise back to the north, therefore, the passage of an eddy can act as a flushing mechanism for the shelf water.

The horizontal and vertical distribution of currents in the nearshore waters was determined from the extremely large amount of current cross and fluorescein dye field surveys conducted over the three year period of this study (Lee, 1968). North currents show a decrease in intensity as the shore is approached and as the bottom is neared. When the western edge of the Florida Current is in close to shore large lateral shears often occur. South currents show a maximum speed on the shelf which decreases in intensity toward the shore and to the east as the center of the eddy is approached. East of the center current direction shifts to the north and the intensity increases to a maximum north speed in the current axis of 4 to 5 knots.

At any point in time and space nearshore currents can be thought of as the vector sum of the current speed and direction induced by the Florida Current, tide and wind forces. The tidal influence will be discussed in a separate section of this report. The Florida Current produces a current to the north or south with average speeds around 0.5 knots and rapid fluctuations ranging from 40 to 70 percent of the mean. Observance of current cross surveys with crosses placed in the surface, 20 feet and 40 feet (Lee, 1968) show the main wind effect is in altering the direction of the surface current. The monthly resultants of wind speed and direction given in Table 11 for West Palm Beach, 1968, show a predominance of onshore (easterly) winds in the Southeast Florida area.

Onshore winds produce a shoreward component in the resultant northerly or southerly currents. The current field surveys show that the water movement in the vicinity of the outfall is normally to the north or south with a small shoreward component depending on the magnitude of the onshore winds. Current cross surveys normally last about 4 hours, therefore, only short term water movements are investigated. Drift cards were used in order to see if the long term effect of the wind induced shoreward component would transport water from the outfall region to shore. Drift cards were released at stations on a line perpendicular to the shore, ten at each station, starting inshore and proceeding east until the Florida Current was reached. A complete listing of the results from these drops is given in Table 12.

The drift card returns were very poor, only 6.7% of the cards released were returned. The larger number of returns from the south reflect the greater number of bathers in the Fort Lauderdale area. In general, the data indicate the typical features of the nearshore currents, i.e. the recovery distance increases as the release distance from shore increases representing a

TABLE 11

Resultant Winds

Month	(degrees) Resultant Direction	(mi/hr) Resultant Speed	Fastest Mile Speed	Fastest Mile Direction	Fastest Mile Date
January	50	3.2	25	30	24
February	280	4.2	32	29	29
March	90	3.5	30	31	1
April	130	4.5	23	5	12
May	120	2.3	12	24	28
June	160	3.8	32	14	11
July	120	2.6	15	10	1
August	110	2.3	13	9	9
September	80	3.5	26	16	10
October	70	4.1	35	13	17
November	40	1.8	31	27	11
December	360	1.6	29	30	4
Average	100	2.5			

TABLE 12

Drift Card Releases

Card #	Release Date	Release Distance	Current Speed & Dir.	Recovery Date	Distance-Direction from drop	Wind Speed (knots)	Wind Direction (from)
10014	9/9/69	4574'	1.05k - N	10/11/69	13 mi.-N	8-10	SE
10074	9/16/69	2700'	.15k - N	9/18/69	1½ mi.-N	4-5	ESE
10077	9/16/69	2700'	.15k - N	9/17/69	1¼ mi.-N	4-5	ESE
10081	9/16/69	4575'	.15k - N	9/22/69	57 mi.-N	4-5	ESE
10116	9/16/69	8700'	.15k - N	9/18/69	23 mi.-N	4-5	ESE
10124	9/16/69	11400'	.15k - N	10/12/69	110 mi.-N	4-5	ESE
10177	10/3/69	4575'	.5k - N	10/11/69	57 mi.-N	7-8	SW
10214	10/10/69	2700'	.7k - S	10/19/69	14 mi.-S	4	N
10218	10/10/69	2700'	.7k - S	10/13/69	13 mi.-S	4	N
10222	10/10/69	4575'	1k - S	10/12/69	13 mi.-S	4	N
10224	10/10/69	4575'	1k - S	10/11/69	10 mi.-S	4	N
10227	10/10/69	4575'	1k - S	10/11/69	14 mi.-S	4	N
10272	11/21/69	2700'	.85k - S	11/29/69	14 mi.-S	4-8	N
10308	11/21/69	7000'	.43k - S	12/29/69	12 mi.-S	4-8	N

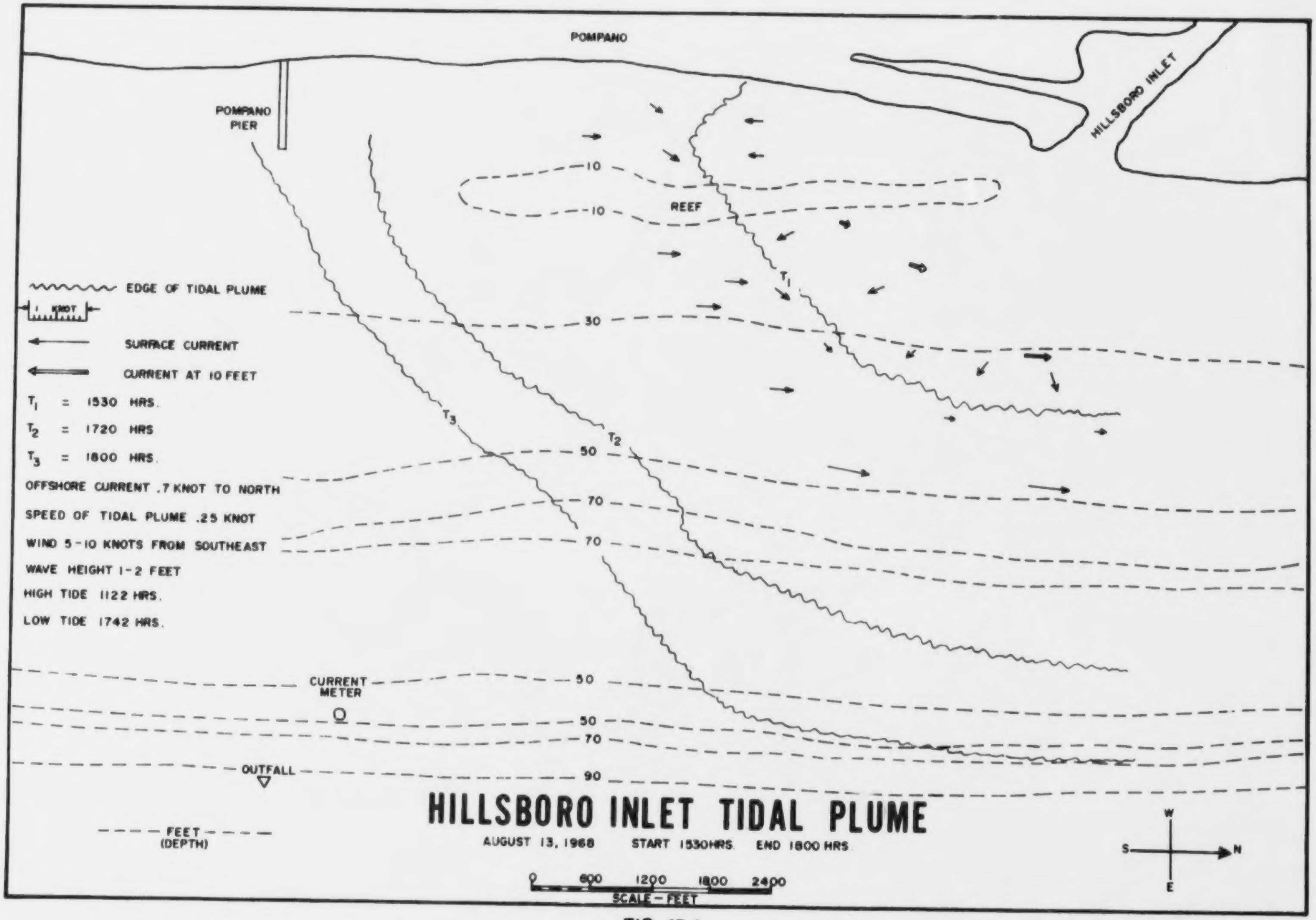
TABLE 12 continued

Card #	Release Date	Release Distance	Current Speed & Dir.	Recovery Date	Distance-Direction from drop	Wind Speed (knots)	Wind Direction (from)
10314	11/21/69	6600'	.23k - S	11/22/69	29 mi.-S	4-8	N
10321	1/16/70	2570'	.4k - S	2/27/70	12 mi.-S	3-4	N
10322	1/16/70	2570'	.4k - S	1/16/70	12 mi.-S	3-4	N
10328	1/16/70	2570'	.4k - S	1/18/70	12 mi.-S	3-4	N
10329	1/16/70	2570'	.4k - S	1/17/70	10 mi.-S	3-4	N
10331	1/16/70	5970'	.2k - SSW	1/17/70	4.2 mi.-N	3-4	N
10334	1/16/70	5970'	.2k - SSW	1/19/70	4.2 mi.-N	3-4	N
10335	1/16/70	5970'	.2k - SSW	1/19/70	4.2 mi.-N	3-4	N
10343	1/16/70	6390'	.2k - NW	1/18/70	8.1 mi.-N	3-4	N

cyclonic shear across the shelf for north currents. Releases into south currents show the cyclonic nature of Florida Current eddies. Cards released on September 16, 1969 and January 16, 1970 first went south then one can assume after some period of time turned east at the end of the eddy then traveled north and eventually came ashore. The cards dropped furthest from shore were recovered the greatest distance north. The cards dropped close to shore on January 16, came ashore before they reached the end of the eddy. Drift card data reveal only a gross idea of the water movements during the time lapse between release and recovery and should be used for no other reason. There is no way of knowing how long the card drifted parallel to shore in the swash and surf zones before beaching, nor how long it lay on the beach before recovery. However, it does indicate that free drifting objects released in the nearshore waters will come ashore at some time and distance dependent upon the circulation features of the area.

TIDAL INLET DISCHARGE

The effect of the Hillsboro and Boca Raton inlets (Fig. 22) on nearshore circulation was discussed in the Second Annual Report. These inlets ebb and flow with a 12.43 hr. period in response to the southerly passage of the principal lunar semidiurnal, progressive tidal wave, down the Florida Straits (Richardson, 1967). Inlet discharge, being less saline and warmer than the shelf waters and therefore less dense, floats above the shelf water as a shallow lens approximately 4 feet deep. The Pompano salinity profiles (Figure 25-45) show the inlet discharge in the inshore waters as a shallow layer extending from 3000 to 6000 feet offshore with salinities 2 - 4‰ less than the shelf water. Those transects are approximately 2 miles south of the inlet showing that Pompano inlet discharge travels south - southeast from the inlet even against a north current on the shelf. Figure 45A from the second annual report (Lee, 1968) is included to show the horizontal movement of the tidal plume. The convergence of currents in the surface produces a sharp color contrast between the dark brown tidal water and the green shelf water. This color contrast made it easy to map the southeast movement of the plume by marking the edge of the plume with a fast boat and shore transits. The inlet plume pushes south because the inlet is discharging in a southeast direction, thus supplying enough momentum to travel south against a north current. Current cross measurements show the plume to be traveling southeast at about 0.25 knots. The north surface currents on the shelf converge with the tide plume, then are diverted toward the north-east around the plume. Subsurface currents travel north unaffected by the tidal plume. The Boca Raton inlet discharges perpendicular to the coast, as does the Fort Lauderdale inlet, therefore the plume extends to the east then travels either north or south depending on the direction of the nearshore currents. A possible solution to reduce the


POMPANO
HILLSBORO INLET
POMPANO PIER
REEF
10
10
30
50
70
70
50
50
70
90
T_1
T_2
T_3
CURRENT METER
OUTFALL
EDGE OF TIDAL PLUME
1 KNOT
SURFACE CURRENT
CURRENT AT 10 FEET
T_1 = 1530 HRS.
T_2 = 1720 HRS
T_3 = 1800 HRS.
OFFSHORE CURRENT .7 KNOT TO NORTH
SPEED OF TIDAL PLUME .25 KNOT
WIND 5-10 KNOTS FROM SOUTHEAST
WAVE HEIGHT 1-2 FEET
HIGH TIDE 1122 HRS.
LOW TIDE 1742 HRS.
FEET (DEPTH)
W
S
N
E
0
600
1200
1800
2400
SCALE – FEET

HILLSBORO INLET TIDAL PLUME

AUGUST 13, 1968 START 1530HRS. END 1800 HRS.

FIG. 45 A

periods of turbid inlet discharge from the Pompano bathing waters would be to reconstruct the Hillsboro inlet to discharge perpendicular to the shelf then the discharge would travel a greater distance offshore before turning north or south with the nearshore currents as evidenced by the Boca Raton and Fort Lauderdale inlets.

CURRENT METER RECORDS

In order to obtain a description of the nearshore circulation that can be systematically analyzed to reveal the effects of the producing forces, long, continuous records of current speed and direction are required. The triangular current meter array at Boca Raton (Figure 23) was put into operation December 6, 1968. These current meters and the current meter at Pompano have been recording with only minor interruptions for servicing and equipment failure since their installation. Each meter records simultaneously in consecutive five minute cycles, 2½ minutes of direction then 2½ minutes of speed. The current meter records from Boca Raton are representative of the water movements throughout the study area. Current meter #2 is positioned relative to the Continental Shelf in the same location as the outfalls of Pompano and Delray and the soon to be completed Boca Raton outfall. The current meters are positioned 25 feet beneath the surface. Comparisons of current cross measurements in the surface and at 25 feet show that currents at this point normally can vary ±0.05 knots from the surface currents. Current direction at 25 feet is approximately the same as the surface. Therefore the current meter data is assumed to be representative of the surface currents. The data from the analog record of current meter #2, over the time period December 6, 1968 to August 11, 1969, was key punched for computer analysis. Fortran programs were developed to provide the following information:

1. For every 10° compass interval:
   a) frequency of observations
   b) mean velocity
   c) standard deviation
   d) variance
   e) percent fluctuation

2. Convert data into the u (east-west) and v (north-south) components.

3. Compute and plot the u and v energy spectrums.

4. Model and predict the u and v tidal currents.

5. Subtract the tidal currents from the actual currents yielding a residual

u and v current.

6. For the u and v currents of the actual, tidal and residual currents compute:
   a) mean velocity
   b) standard deviation
   c) variance
   d) percent fluctuation
   e) percent positive
   f) percent negative
   g) mean positive
   h) mean negative

7. Plot the actual, tidal and residual for both the u and v component current.

The current speed and direction data for every 10° compass interval can be displayed graphically with the current roses of Figures 46-54. The mean current speed in knots for each interval is shown at the ends of the protruding observation arms. The most striking feature of the current rose drawings is the predominance of north and south currents with speeds of the same magnitude. Currents to the east and west are less frequent with speeds approximately one half that of the north-south currents. There appears to be a seasonal variation of speed of the north-south currents. Minimum speeds occur during January and increase to a maximum around the end of July. The abnormal grouping of currents to the east shown in Figures 25, 28 and 29 are not real features of the currents. The break point on the current direction potentiometer sensor was set on east, therefore, east currents produce large fluctuations on the readout. The person taking off data has a tendency to call large fluctuations in direction an east current. In actuality the east current should be spread out over an interval from 70° to 110°.

The currents of interest in terms of determining the shoreward movement of water from the vicinity of the outfall are the negative u component (west) of the current velocity, therefore, the current velocity vectors were resolved into the north-south (v component) and east-west (u component) currents. A positive v component would be a current to the north and negative v to the south. A positive u component indicates an east current and negative u is to the west.

Statistical computations were made on the data used to construct the current rose drawings and are presented in Table 13. The v component table shows 62% of the v component currents are to the north with a mean of 0.45 knots and 31% to the south with a -0.39 knot mean. The u component shows 47% of the u components to the east and 47% to the west with means of 0.17 and -0.16 knots respectively. The seasonal variation of current speed is clearly evident. A minimum +v component of 0.20 knots occurs in late January and a maximum of 0.70 knots in late July. This represents a seasonal fluctuation of 55%

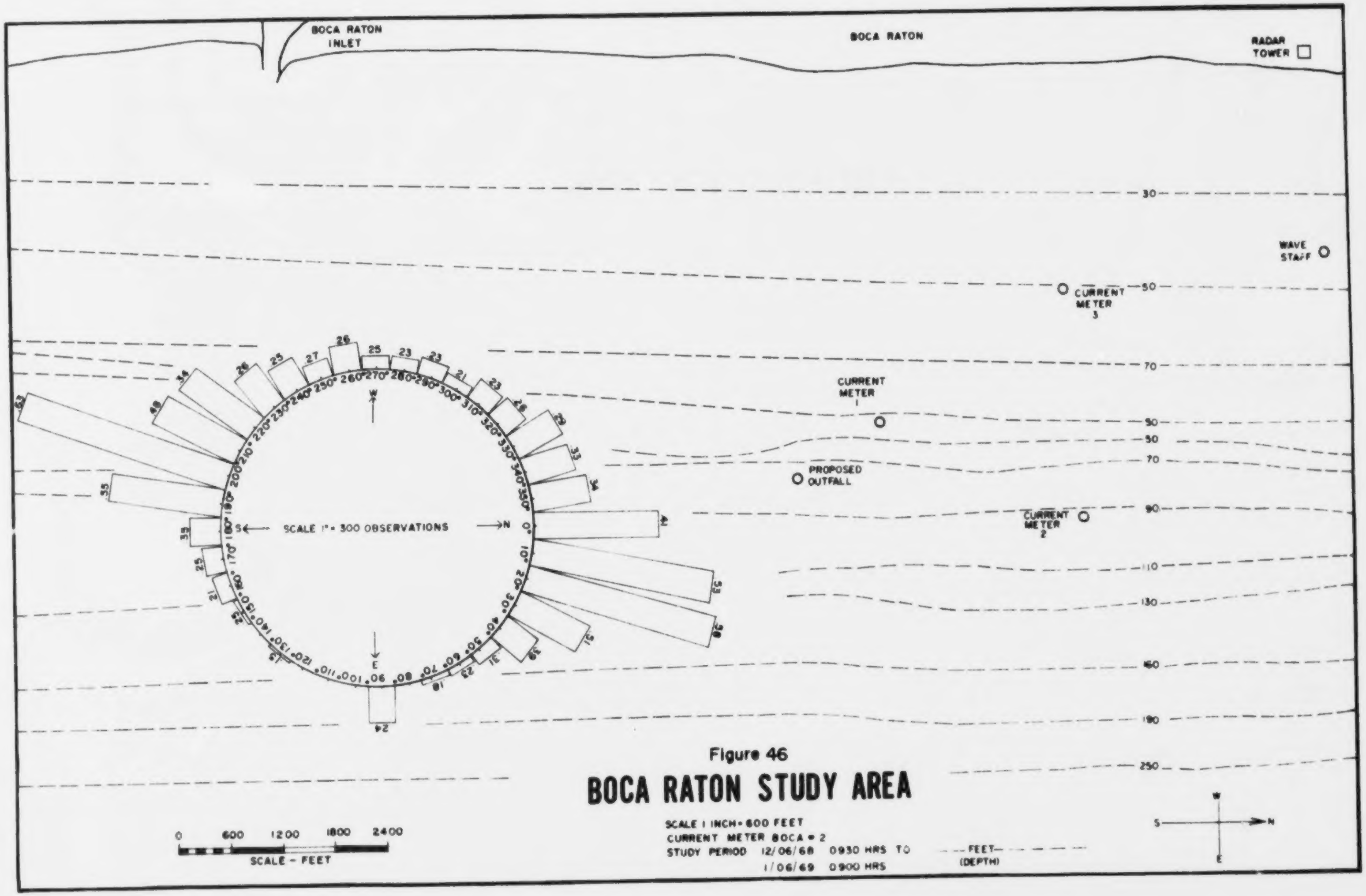


Figure 46

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA # 2
STUDY PERIOD 12/06/68 0930 HRS TO
1/06/69 0900 HRS

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
PROPOSED OUTFALL
CURRENT METER 2
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1" = 300 OBSERVATIONS
N
S
E
W
0° 10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180° 190° 200° 210° 220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320° 330° 340° 350°
41 53 58 31 39 31 23 18 24 13 23 21 25 39 55 48 63 34 26 25 27 26 25 23 23 21 23 28 29 33 34
0 600 1200 1800 2400
SCALE - FEET
FEET (DEPTH)

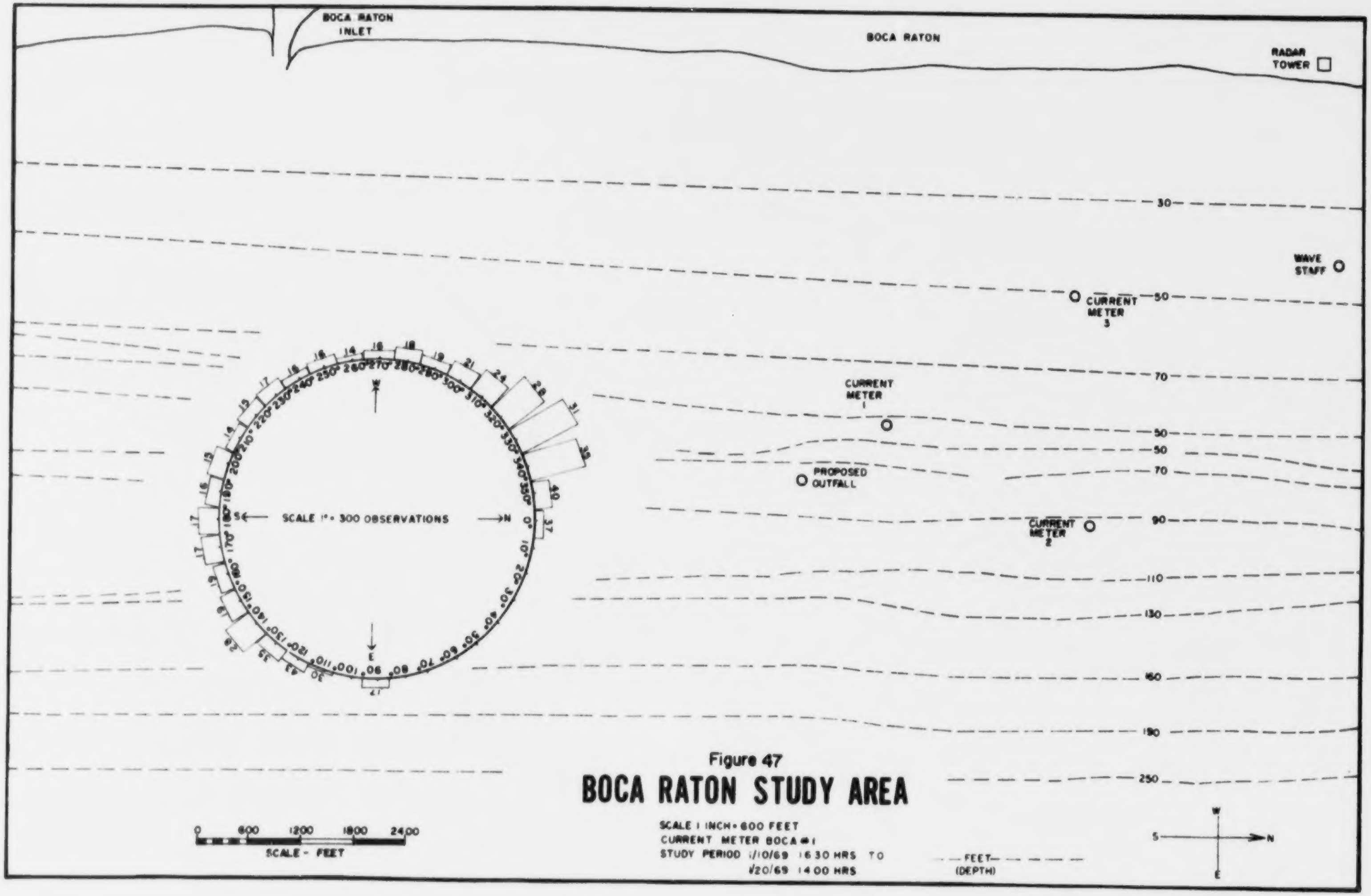

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
PROPOSED OUTFALL
CURRENT METER 2
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1° = 300 OBSERVATIONS
N
S
E
W
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
37
40
39
31
28
24
21
19
18
16
14
16
18
17
15
14
15
16
17
17
19
19
28
33
43
30
0 600 1200 1800 2400
SCALE - FEET
FEET (DEPTH)

Figure 47

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA #1
STUDY PERIOD 1/10/69 1630 HRS TO
1/20/69 1400 HRS

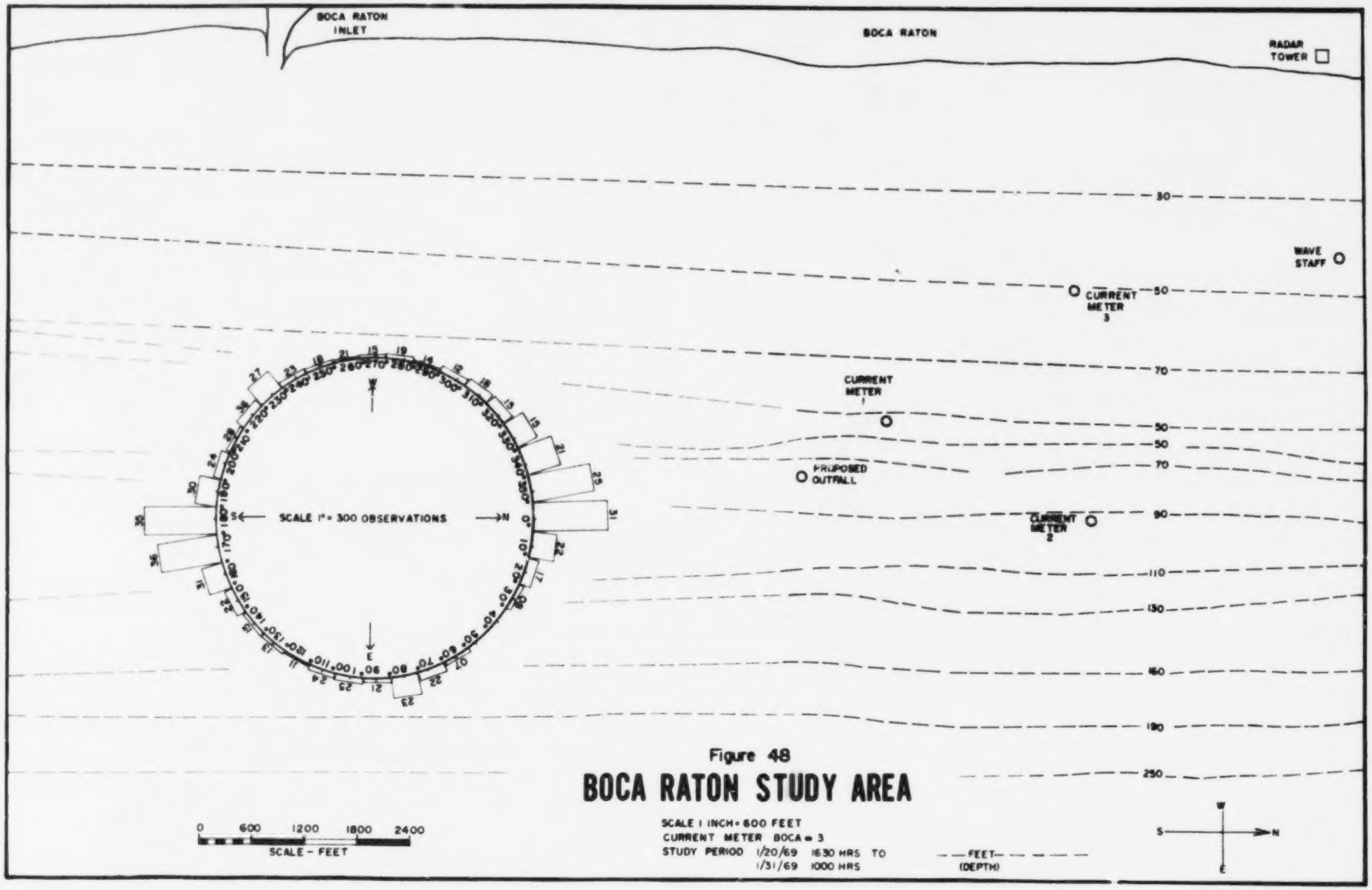

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
CURRENT METER 2
PROPOSED OUTFALL
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1" = 300 OBSERVATIONS
N
S
E
W
0 600 1200 1800 2400
SCALE - FEET
— FEET — (DEPTH)
S
N
W
E

Figure 48

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA = 3
STUDY PERIOD 1/20/69 1630 HRS TO
1/31/69 1000 HRS

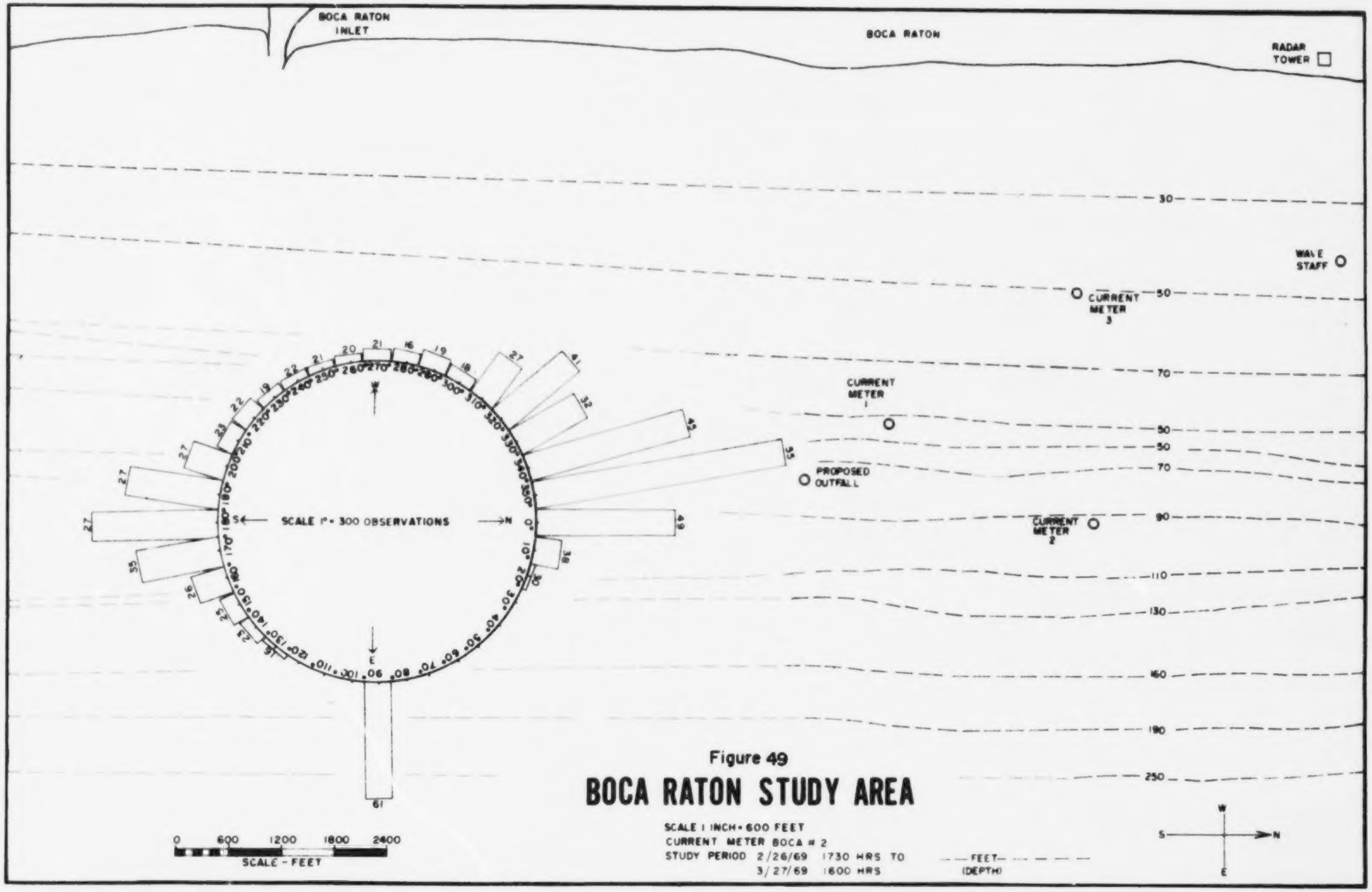

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
PROPOSED OUTFALL
CURRENT METER 2
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1" = 300 OBSERVATIONS
N
S
W
E
0 600 1200 1800 2400
SCALE - FEET
FEET (DEPTH)

Figure 49

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA # 2
STUDY PERIOD 2/26/69 1730 HRS TO
3/27/69 1600 HRS

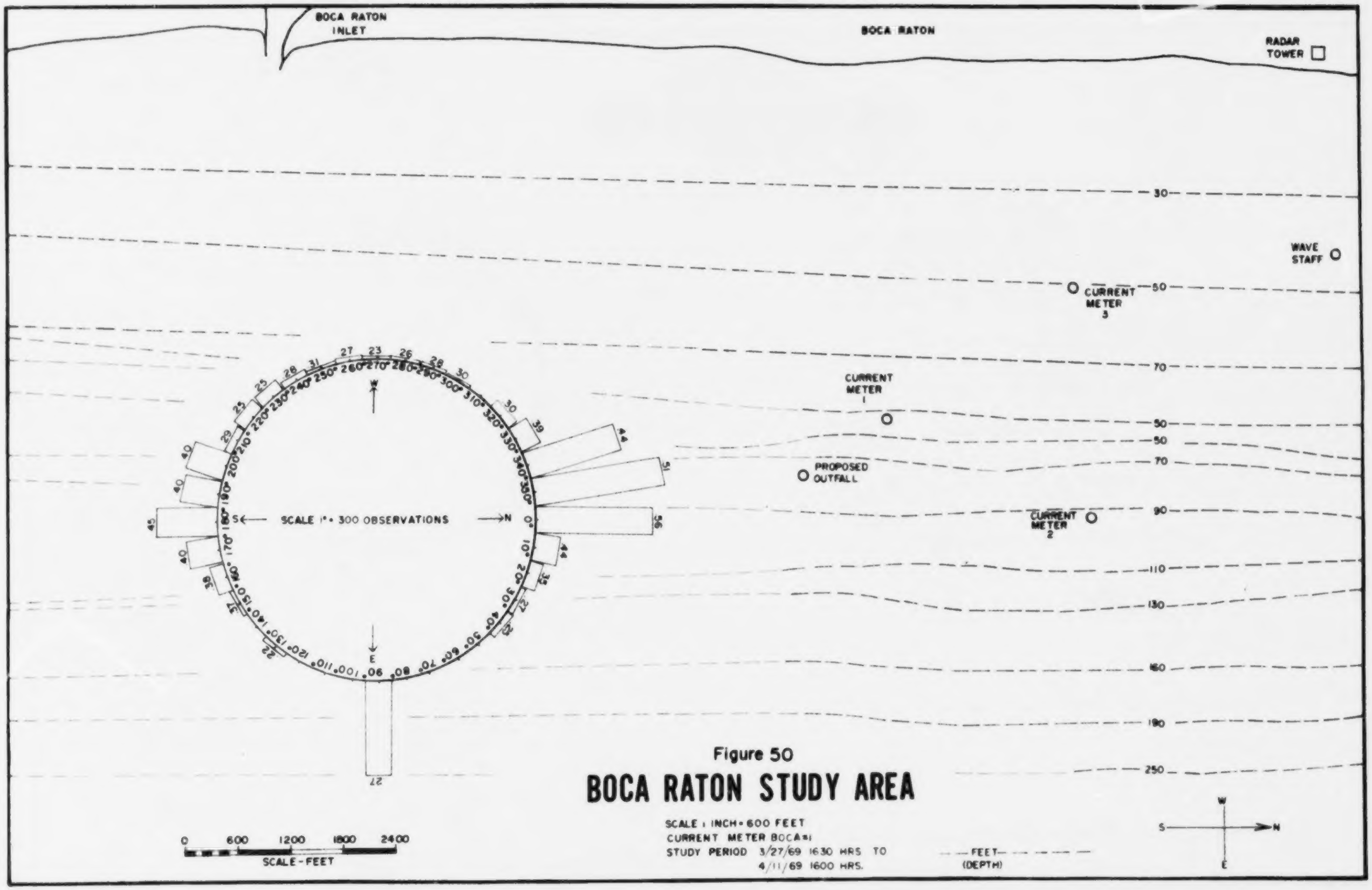

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
PROPOSED OUTFALL
CURRENT METER 2
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1" = 300 OBSERVATIONS
S
N
W
E
0° 10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180° 190° 200° 210° 220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320° 330° 340° 350°
56
44
35
27
23
27
22
37
38
40
45
40
40
29
25
25
28
31
27
23
26
28
30
30
39
44
51
0
600
1200
1800
2400
SCALE-FEET
--- FEET ---
(DEPTH)
W
S
N
E

Figure 50

BOCA RATON STUDY AREA

SCALE: 1 INCH = 600 FEET
CURRENT METER BOCA #1
STUDY PERIOD 3/27/69 1630 HRS TO
4/11/69 1600 HRS.

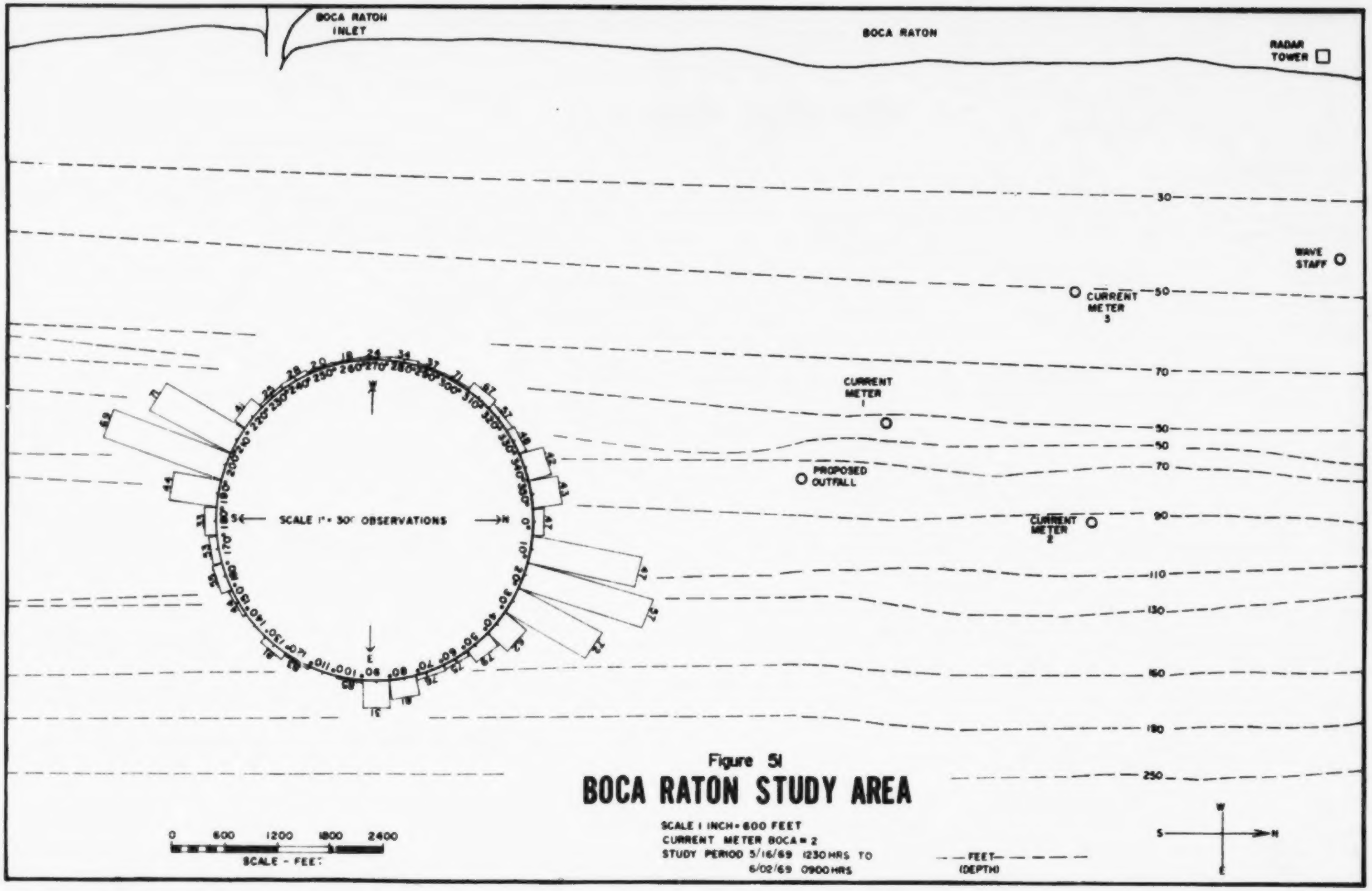

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
PROPOSED OUTFALL
CURRENT METER 2
30
50
70
90
50
70
90
110
130
160
180
250
SCALE 1" = 30 OBSERVATIONS
S
N
W
E
0
600
1200
1800
2400
SCALE - FEET
FEET (DEPTH)

Figure 51

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA = 2
STUDY PERIOD 5/16/69 1230 HRS TO
6/02/69 0900 HRS

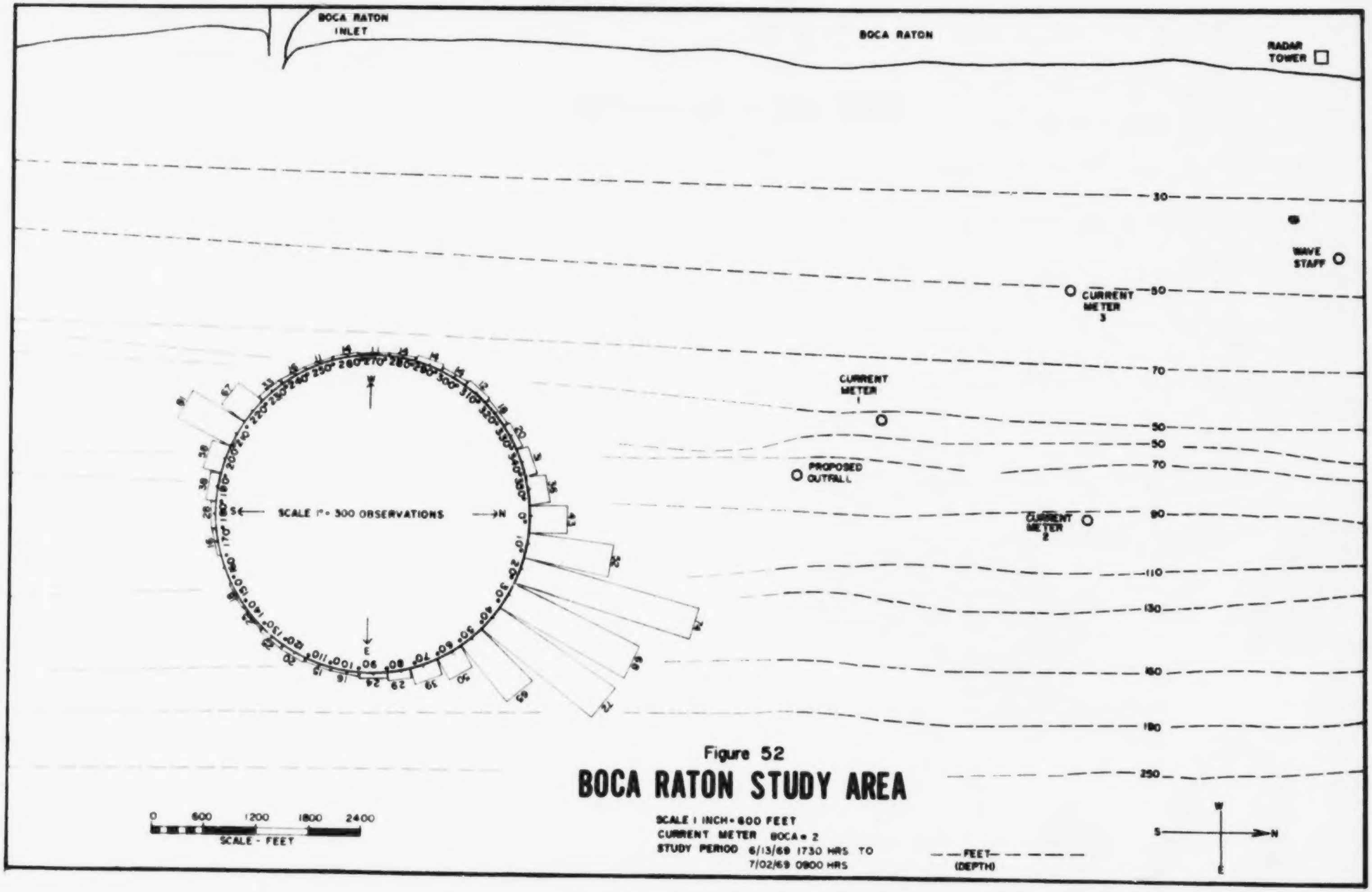

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
PROPOSED OUTFALL
CURRENT METER 2
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1" = 300 OBSERVATIONS
N
S
E
W
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
43
52
74
68
72
65
40
39
29
24
16
13
20
23
18
15
28
38
38
91
67
33
15
11
14
11
13
14
14
12
18
20
5
35
0
600
1200
1800
2400
SCALE - FEET
FEET
(DEPTH)

Figure 52

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA = 2
STUDY PERIOD 6/13/69 1730 HRS TO
7/02/69 0800 HRS

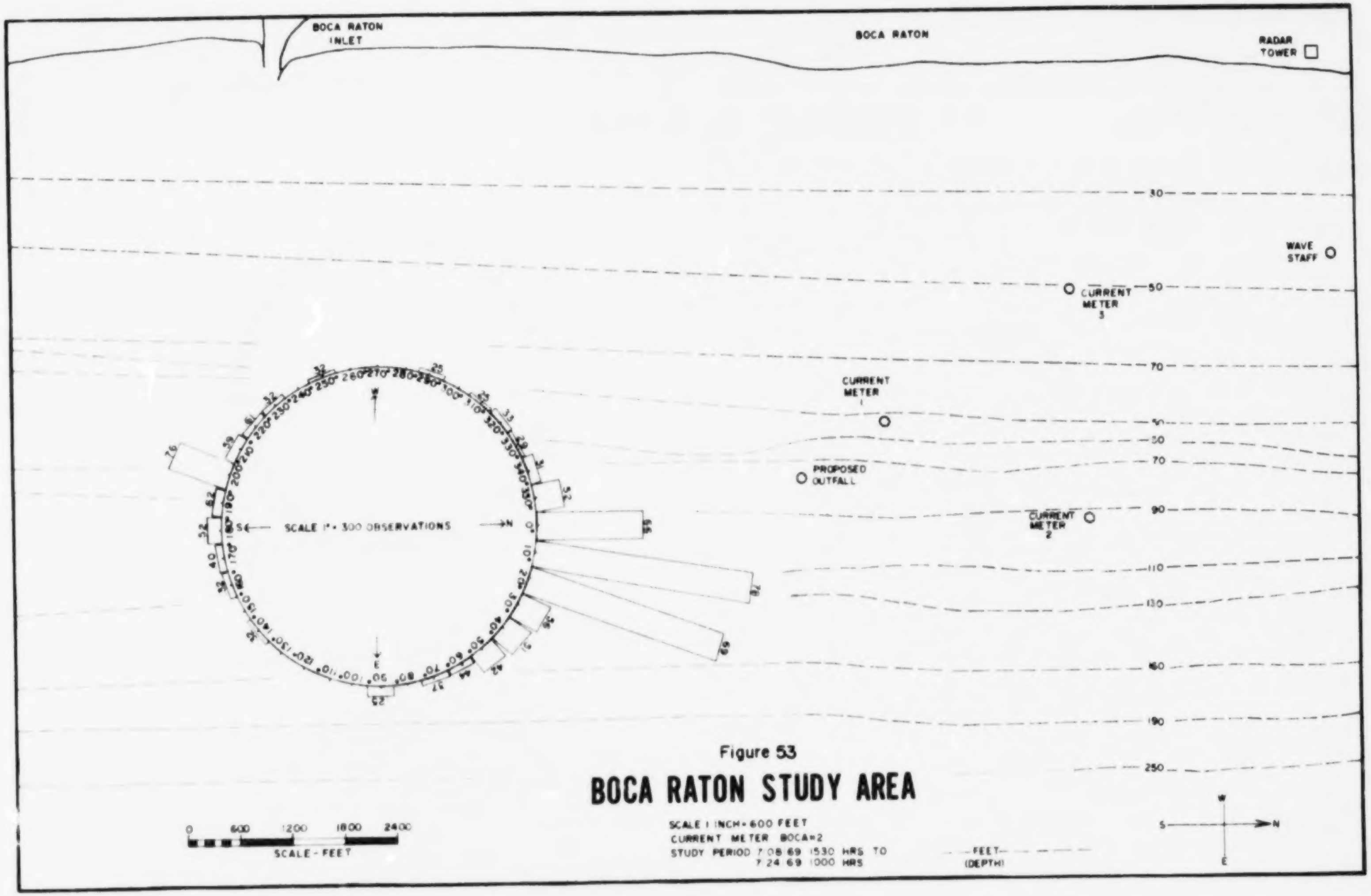

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
CURRENT METER 2
PROPOSED OUTFALL
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1" = 300 OBSERVATIONS
N
S
E
W
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
55
78
69
56
51
42
44
37
25
32
40
32
62
76
59
61
32
32
25
25
33
29
31
52
0
600
1200
1800
2400
SCALE - FEET
FEET (DEPTH)

Figure 53

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA=2
STUDY PERIOD 7/08/69 1530 HRS TO
7/24/69 1000 HRS

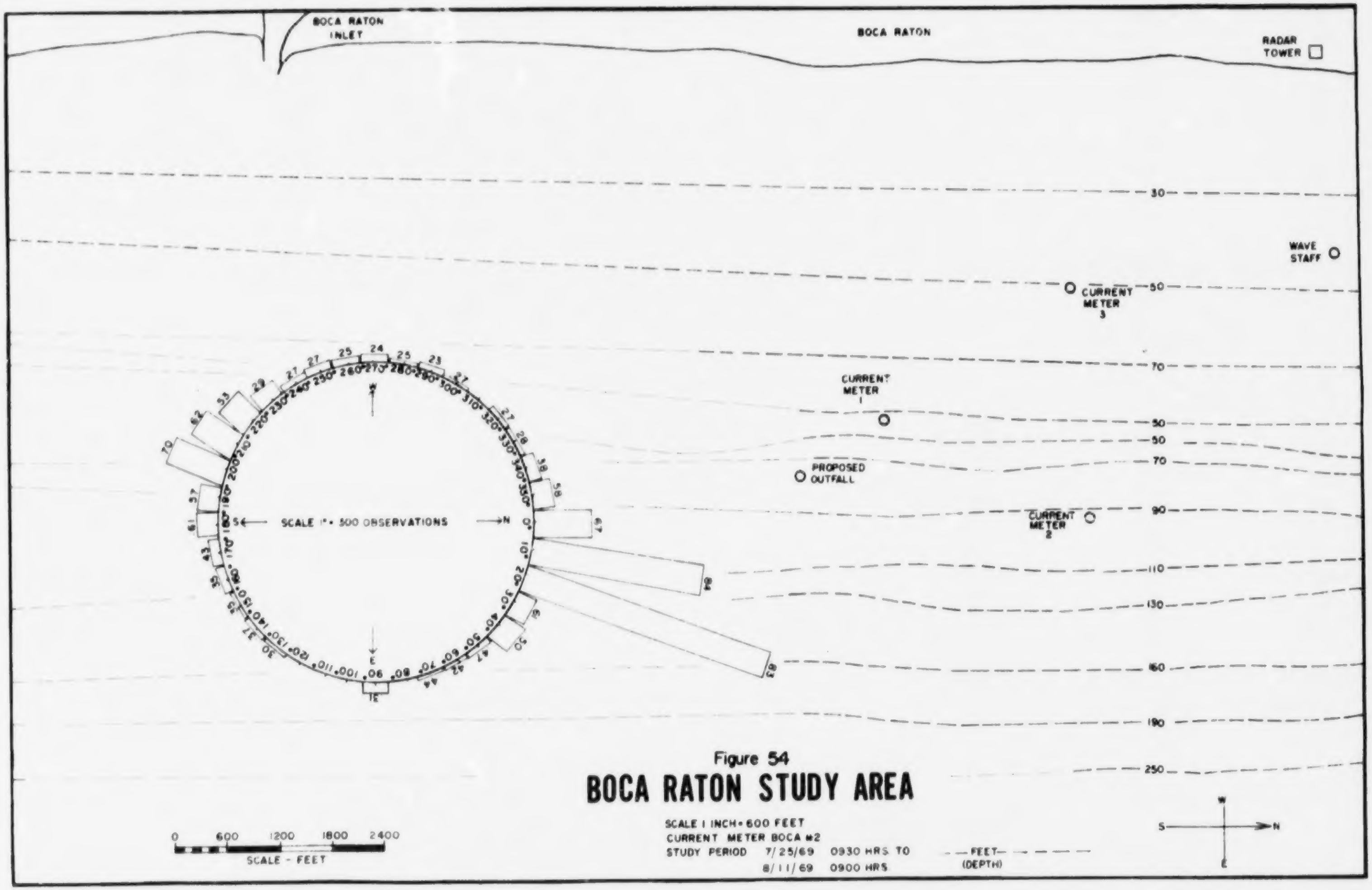

BOCA RATON INLET
BOCA RATON
RADAR TOWER
WAVE STAFF
CURRENT METER 3
CURRENT METER 1
PROPOSED OUTFALL
CURRENT METER 2
30
50
70
50
50
70
90
110
130
160
190
250
SCALE 1" = 300 OBSERVATIONS
N
S
E
W
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°
67
84
83
61
50
47
42
44
31
30
37
33
35
43
61
57
70
62
53
29
27
27
25
24
25
23
27
27
28
38
58
0
600
1200
1800
2400
SCALE - FEET
FEET (DEPTH)
W
S
N
E

Figure 54

BOCA RATON STUDY AREA

SCALE 1 INCH = 600 FEET
CURRENT METER BOCA #2
STUDY PERIOD 7/25/69 0930 HRS TO
8/11/69 0900 HRS

TABLE 13

Current Meter Data Statistics

v - Component (knots)

Date	Mean Velocity	Standard Deviation	Variance	% Positive	% Negative	Mean Positive	Mean Negative
12/6 - 1/6	.06	.47	.22	57	40	.40	-.43
1/10 - 1/20	.05	.23	.05	51	45	.24	-.16
1/20 - 1/31	-.02	.27	.07	48	43	.20	-.28
2/26 - 3/27	.15	.36	.13	58	33	.41	-.25
3/27 - 4/11	.15	.41	.17	57	30	.46	-.35
5/16 - 6/2	.10	.55	.30	60	35	.49	-.56
6/13 - 7/2	.34	.46	.22	80	17	.52	-.47
7/8 - 7/24	.43	.52	.28	82	16	.64	-.55
7/25 - 8/11	.36	.59	.35	69	28	.70	-.46

u - Component (knots)

Date	Mean Velocity	Standard Deviation	Variance	% Positive	% Negative	Mean Positive	Mean Negative
12/6 - 1/6	-.03	.20	.04	41	55	.16	-.17
1/10 - 1/20	-.05	.15	.02	27	71	.14	-.13
1/20 - 1/31	-.01	.10	.01	38	50	.08	-.06
2/26 - 3/27	-.06	.13	.02	26	71	.09	-.11
3/27 - 4/11	-.03	.15	.02	30	61	.15	-.11
5/16 - 6/2	.04	.29	.09	53	43	.25	-.23
6/13 - 7/2	.19	.31	.10	76	22	.32	-.25
7/8 - 7/24	.10	.19	.04	71	21	.19	-.18
7/25 - 8/11	.07	.23	.05	63	31	.22	-.22

of the mean northerly current. Based on previous results of investigations of the Gulf Stream this seems excessively high. Fuglister (1948), reported a seasonal fluctuation of 14% of the mean, Hela (1952), found 10% and Richardson (1967) also concluded 10% as an upper bound for seasonal fluctuations. However, these investigations were all conducted within the stream where the average fluctuation is only 9.23% of the mean (Smith, Zetler and Broida, 1969). During July the trade winds intensify due to the increased pressure gradient of the Bermuda-Azores High (Stommel, 1965). This increase in the circulation of the North Atlantic wind system in the summer may be responsible for the increase in the nearshore current speeds in late July, however, this is merely speculation. A seasonal fluctuation of 10% of the mean speed in the Florida Current would be magnified in the shelf waters, for not only would the speed of the Florida Current be greater but the western boundary would spread laterally. Thus, the western edge of the Florida Current would be closer to current meter #2 for a greater amount of time in July, therby, accounting for a high seasonal fluctuation of 55% of the mean.

The u component data show that west currents have the lowest speeds of any direction (-0.16 mean). The current speed must be considered in conjunction with the duration in order to see the effect of west currents in transporting water shoreward from the region of the Pompano outfall. Negative u components are produced by two means: 1) The start of a Florida Current eddy when current direction cycles counterclockwise through west, which is of relatively short duration (1-2 hours); 2) As the east-west component of a steady, resultant current at some angle to the west from north or south. The west component of a northwest or southwest current can last for long periods of time. Figure 55 is a typical plot of the u and v components of the actual (observed) currents taken from current meter #2 computer print-out. The component to the west lasts for 38 hours with speeds from -0.02 to -0.38 knots. Using a mean u component of -0.2 knots for west currents, it would take 6 hours for effluent from the Pompano outfall to reach shore. Figures 46-54 show that current vectors in the direction of 200° make up a large percent of the total number of observations. This is because a current vector of 200° is produced by the passage of a Florida Current eddy, which occurs quite frequently. During an eddy, the water movement at current meter #2 is predominately in the direction of 200° advecting Florida Current water onto the shelf. The normal situation is for the currents to shift to a southerly direction as the shore is approached, thus, decreasing the speed of the west current and either increasing the travel time of effluent before it reaches the bathing areas or diverting it away from the bathing areas. At the southern end of an eddy the current direction changes to east and eventually to the north with the Florida Current.

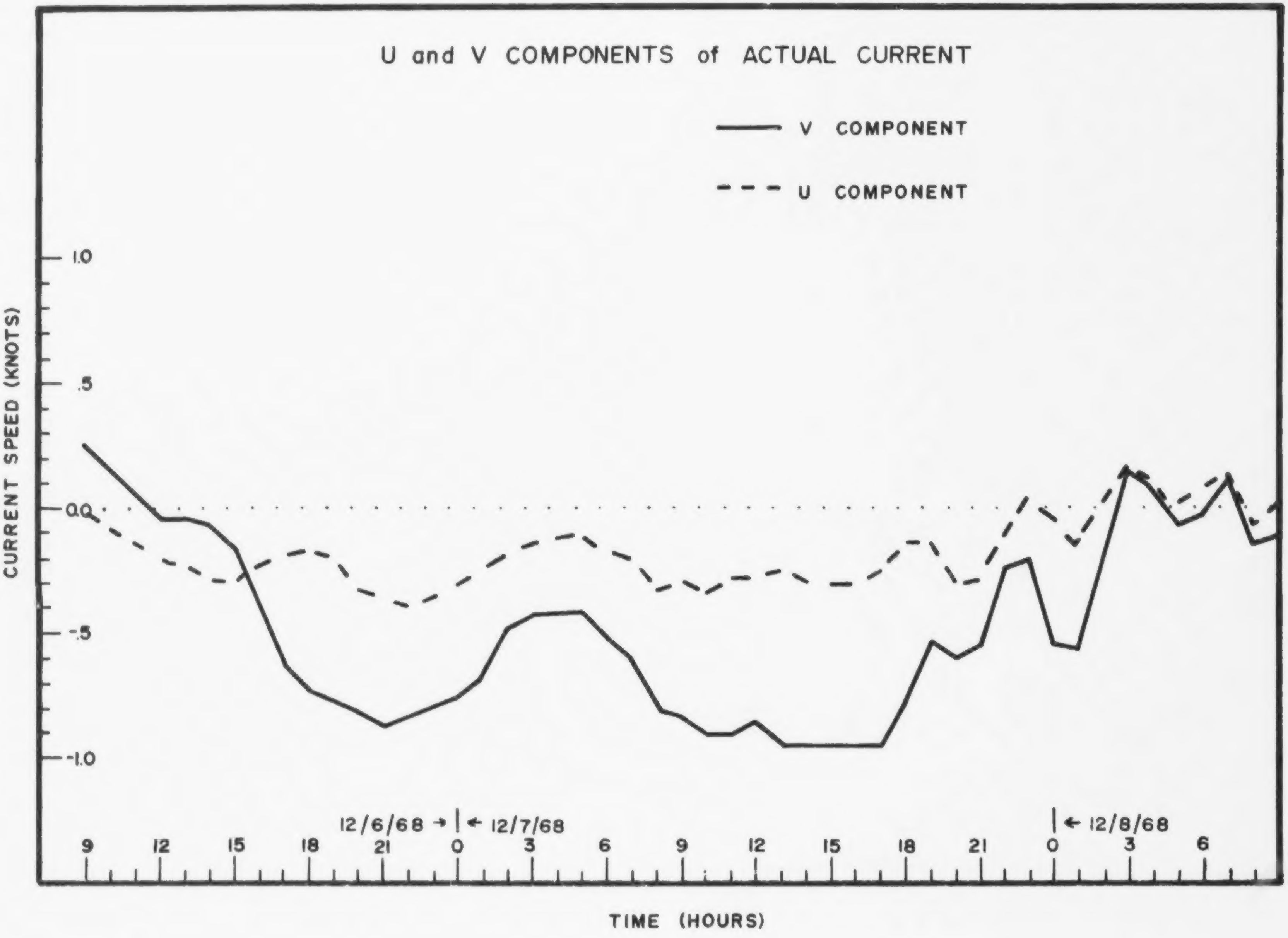

U and V COMPONENTS of ACTUAL CURRENT
V COMPONENT
U COMPONENT
CURRENT SPEED (KNOTS)
1.0
.5
0.0
-.5
-1.0
12/6/68 →
← 12/7/68
← 12/8/68
9
12
15
18
21
0
3
6
9
12
15
18
21
0
3
6
TIME (HOURS)

Fig. 55

TIDAL ANALYSIS

Current meter data from Pompano and Boca Raton consistently show large fluctuations in both speed and direction. These fluctuations can be seen in both the large standard deviations of Table 13 or graphically in Figure 55.

Tidal currents are produced by the periodic variation of mean sea level associated with a large number of tide producing forces. Both the tidal forces and resulting currents vary as simple periodic motions, therefore, tidal currents are seen in a spectral analysis of time series data as a peak of energy at the associated tidal frequency.

Energy spectra for the u and v components (Lee, 1968) were computed and plotted for each set of data given in Table 13, using the program developed by Mannring and Tennant (1968), in order to determine if there was any periodicity to the observed fluctuations. The spectrums revealed that approximately 90% of the energy is associated with periods greater than 20 hours. There is an absence of any predominate peaks associated with particular frequency bands. The spectra suggest that the large scale fluctuations present in the data are aperiodic. However, because of the accumulation of energy in the near tidal and long period motions, the amount of tidal influence in the variations could not be concluded from energy spectrums.

A harmonic analysis of the current records was performed in order to separate the tidal effects and predict the tidal currents. The actual tide producing force is a linear combination of the amplitude and phase of each constituent force. Although there may be a great number of constituent forces the tide producing force can be reliably estimated using only the five major tidal components listed in Table 14 (Durham, et al, 1967).

The Coast and Geodetic Survey, Rockville, Maryland conducted a harmonic analysis on a 29 day current meter record from Pompano, to obtain the amplitude and phase of the 24 most significant constituents. The results for the five major constituents are given in Tables 15 and 16.

Tidal currents in the nearshore waters are predominantly in a north-south direction. Since tidal changes in sea level are strictly semi-diurnal in the Florida Straits, it is surprising to find that diurnal tidal currents are of the same magnitude as the semi-diurnal currents are present. This was explained by Zetler (1968), as the result of a longitudinal diurnal standing wave joining the Gulf of Mexico to the Atlantic Ocean with a node near Miami. If this hypothesis is true, then the K (1) phase angle near the node should be 90° earlier than the K (1) tide of the Gulf of Mexico. Smith, et al (1969), using data from the monster buoy anchored in the Florida

TABLE 14

PRINCIPLE HARMONIC COMPONENTS OF THE TIDE

Name of Component	Symbol	Period (hours)
Principle Lunar Semi-diurnal	M(2)	12.43
Principle Solar Semi-diurnal	S(2)	12.00
Larger Lunar Elliptic Semi-diurnal	N(2)	12.66
Luni-Solar Diurnal	K(1)	23.43
Lunar Diurnal	O(1)	25.82

TABLE 15

v - Component (north-south)

Constituent	Phase (degrees)[*]	Amplitude (knots)
M(2)	110.27	0.060
N(2)	337.16	0.020
S(2)	57.13	0.042
O(1)	20.82	0.054
K(1)	31.21	0.064

---

[*] These phases are all referred to tidal flow to the north; to determine the flow to the south apply ± 180°.

TABLE 16

u - Component (east-west)

Constituent	Phase (degrees)*	Amplitude (knots)
M(2)	352.83	0.020
N(2)	282.14	0.004
S(2)	29.26	0.007
O(1)	331.35	0.012
K(1)	285.74	0.021

---

* These phases are all referred to tidal flow to the north; to determine the flow to the south apply ± 180°.

Current off Hollywood, Florida calculated a K (1) phase angle of 284°, referred to the Greenwich meridian. This is approximately 90° earlier than the 20° Greenwich phase for K (1) in the Gulf of Mexico. The Greenwich phase for K (1) from the Pompano current meter data (v component) is 291°, which is in good agreement with Smith and approximately 90° earlier than the 20° Greenwich phase for the Gulf of Mexico, thus supporting the standing wave hypothesis. Pompano, being near the node experiences large diurnal currents without a diurnal change in sea level. The semi-diurnal currents are due to the semi-diurnal progressive tidal wave moving through the Florida Straits from north to south.

Tidal current predictions for the u and v velocity components using the ten largest constituents from the harmonic analysis were performed on the data records from Pompano and Boca Raton using the following model (Schureman, 1958):

$$V_i = \sum_{i=1}^{10} H_i \cos (a_i t + \alpha_i) \qquad (1)$$

where i is the subscript for each constituent; H is the constituent amplitude; a is the speed of the constituent; t is time; and $\alpha =$ Greenwich $(V_o + u) + \frac{aS}{15} - pL - K$ in which:

S = west longitude in degrees, of time meridian used at this station.

L = west longitude in degrees of station for which predictions are desired.

P = 0 when referring to the long period constituents.

P = 1 when referring to the diurnal constituents.

P = 2 when referring to the semi-diurnal constituents, etc.

K = phase lag of constituent.

Greenwich $(V_o + u)$ = Equilibrium argument $(V_o + u)$ for meridian of Greenwich.

Equation (1) will therefore predict at any time (t) the amplitudes of the u and v tidal currents.

Computer plots were constructed of: the u and v observed currents at Pompano and Boca Raton; the predicted tidal currents; and the residual currents obtained by subtracting the predicted tidal current from the actual current. Figure 56 is a representative plot of the v component current for two days of the 29 day record from Pompano. This plot shows the large variations in current speed and direction which are typical of the area. The actual current shows strong currents to the south lasting 20

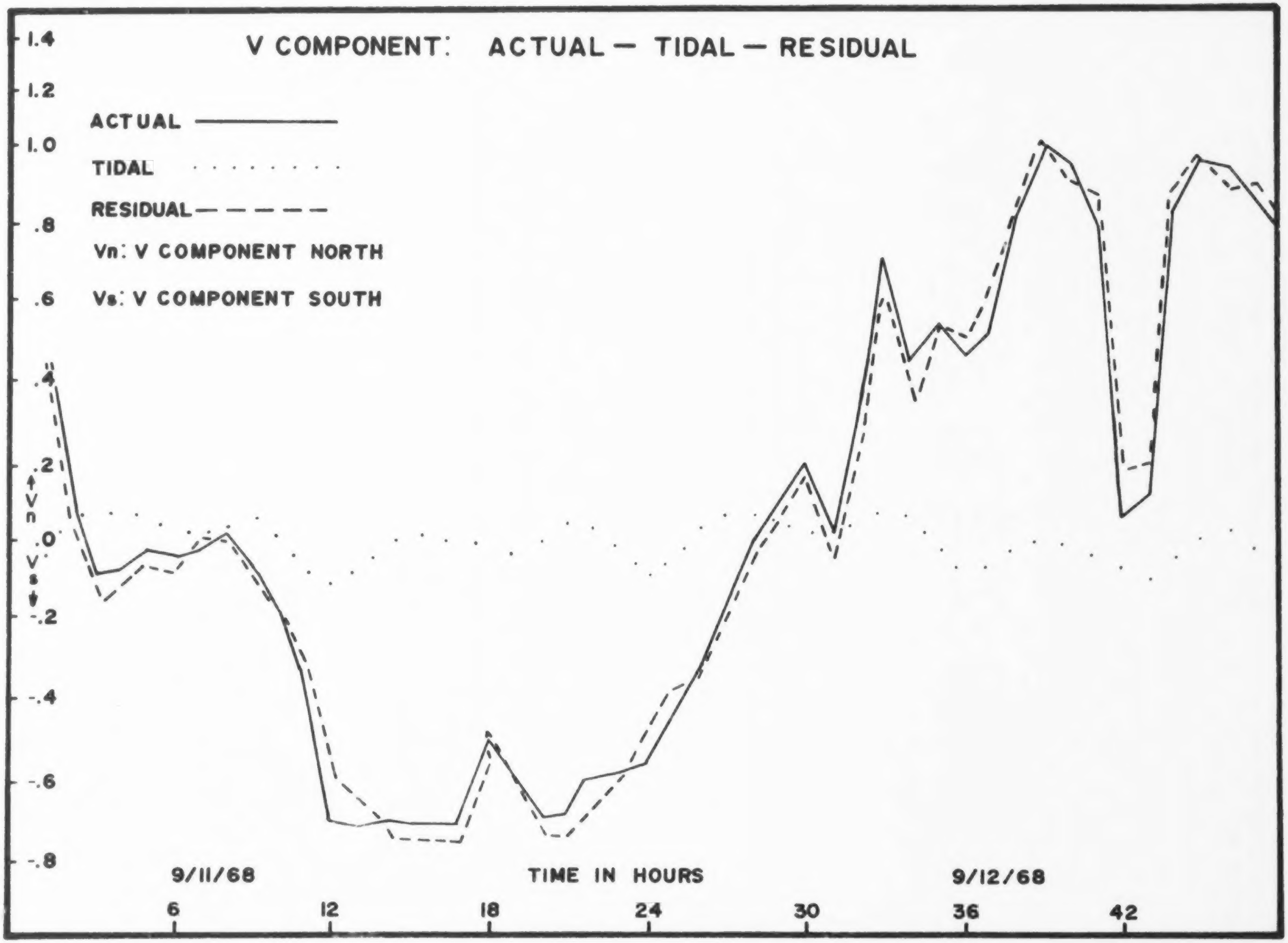

V COMPONENT: ACTUAL — TIDAL — RESIDUAL
ACTUAL
TIDAL
RESIDUAL
Vn: V COMPONENT NORTH
Vs: V COMPONENT SOUTH
1.4
1.2
1.0
.8
.6
.4
.2
↑Vn
.0
Vs↓
-.2
-.4
-.6
-.8
9/11/68
TIME IN HOURS
9/12/68
6
12
18
24
30
36
42

Fig. 56

hours. These strong south currents represent the northward passage of a Florida Current eddy. The actual and residual currents are practically exact images indicating that the tidal contribution to the actual currents is small. The tidal current curve shows the mixed nature of the tides with semidiurnal and diurnal fluctuations present, which are, for the most part, out of phase with the fluctuations of the actual current.

Smith et al, (1969), calculated a fluctuation of 10% of the mean surface current as representative of the Florida Current. The percent of these fluctuations due to tides was found to be 21.35%. The nearshore currents show a mean v component of approximately 0.50 knots for either north or south currents and a mean u component of about 0.20 knots for east or west currents (Table 13). The average fluctuation of the observed current ranges from 40 to 70 percent of the mean, determined by dividing the standard deviation by the mean velocity for each 10° compass interval. The percent of the modulations in the observed currents due to tides is given in Table 17 and 18. The percent of the total current fluctuations due to tidal current fluctuations is approximately 4.8% for the v component and 2.7% for the u component. It is apparent that tidal currents are insignificant to nearshore circulation in the southeast Florida area. The combination of a narrow continental shelf and the presence of a strong offshore current which is meandering laterally into the shelf waters and producing eddies which pass over the shelf produces large variations in current speed and direction in the nearshore currents which mask tidal variations.

FLORIDA CURRENT EDDIES

The frictional interaction of the western boundary of the Florida Current with the Continental Shelf produces large lateral current shear, meandering, and spin-off eddies. These non-linear effects make it very difficult to solve the governing equations of motion. Although the dynamics of this region are not well understood it is believed that instabilities develop in the shear region which grow into eddies and are advected northward by the Florida Current.

The current meter data from Pompano and Boca Raton show the northward passage of an eddy as a counterclockwise cycle of the current vector. The time of passage (duration) of an eddy may be from a few hours to 60 hours with speeds to the south ranging from -0.2 to -1.5 knots. Boca Raton current meter data over the period from December 6, 1968 through September, 1969 show the passage of 163 eddies in 270 days, i.e. approximately 4 eddies/week.

Figure 56A shows the spatial characteristics of a hypothetical eddy that was first presented in the second annual report

TABLE 17

Tidal Fluctuations: v - Component

Date	Actual Current Variance	Tidal Current Variance	% Fluctuation due to tides
12/6 - 1/6	.2229	.0077	3.45
1/10 - 1/20	.0515	.0057	11.10
1/20 - 1/31	.0720	.0058	8.06
2/26 - 3/27	.1327	.0074	5.58
3/27 - 4/11	.1692	.0076	4.40
5/16 - 6/2	.2999	.0081	2.71
6/13 - 7/2	.2153	.0077	3.25
7/8 - 7/24	.2751	.0078	2.84
7/25 - 8/11	.3514	.0080	2.28

TABLE 18

Tidal Fluctuations: u - Component

Date	Actual Current Variance	Tidal Current Variance	% Fluctuation due to tides
12/6 - 1/6	.0383	.0008	2.09
1/10 - 1/20	.0234	.0007	2.99
1/20 - 1/31	.0104	.0007	6.73
2/26 - 3/27	.0176	.0007	3.98
3/27 - 4/11	.0227	.0008	3.52
5/16 - 6/2	.0875	.0008	0.91
6/13 - 7/2	.0971	.0008	0.82
7/8 - 7/24	.0363	.0008	2.20
7/25 - 8/11	.0547	.0008	1.46

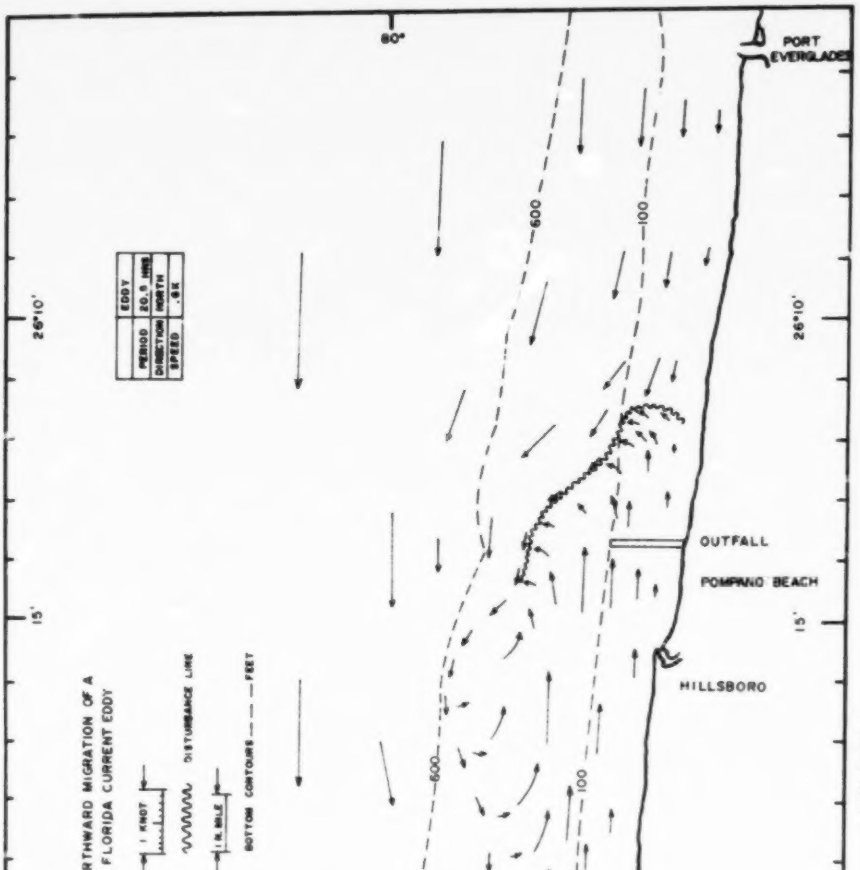

NORTHWARD MIGRATION OF A
FLORIDA CURRENT EDDY
1 KNOT
DISTURBANCE LINE
1 N. MILE
BOTTOM CONTOURS — — — FEET
EDDY
PERIOD 20.5 HRS
DIRECTION NORTH
SPEED .6K
S
E
W
N
80°
26°10'
15'
20'
26°25'
600
100
PORT EVERGLADES
OUTFALL
POMPANO BEACH
HILLSBORO
PROPOSED OUTFALL
BOCA RATON
OUTFALL
DELRAY BEACH

FIG. 56A

(Lee, 1968). This eddy was constructed from current cross observations at the start, middle and end of different eddies and from current meter records taken over the same period. Although current reversals can be explained by the northward passage of a meander or wave in the Florida Current or as a coastal counter current, the eddy concept is preferred based on field observations of currents, temperature and salinity. During periods of south currents the temperature, salinity, water color and clarity were representative of the Florida Current, indicating that shelf waters were being replaced by water from the Florida Current and the reversals were not simply coastal counter currents. Current cross observations at the southern end of eddies have shown the existance of a disturbance line, formed where south currents in the eddy converge with northerly moving shelf water, producing a turbulent rip of easterly currents. This disturbance line was traveling north at approximately 0.6 knots. It was hard to conceive of a progressive wave producing this type of convergence and/or horizontal distribution of temperature and salinity.

The cyclonic nature of an eddy will transport water from the Florida Current onto the shelf at the beginning of the eddy and transport the shelf water offshore at the end. Thus, the passage of an eddy can act as a flushing mechanism for the shelf waters. The flushing capability or the ability to remove and dilute pollutants will depend on the size, strength and phase speed of the eddy. This can be thought of in terms of the duration of an eddy as seen from current meter records. The greater the duration then the greater the size of the eddy and the amount of time for transporting shelf water offshore. Observations of water clarity and current meter records indicate that an eddy lasting 16 hours or greater with maximum southerly speeds greater than -0.6 knots can flush the shelf waters. Current meter records show that the frequency of occurance of eddies with the above duration and speeds ranges from 1 to 9 days. Therefore, the residence time or length of time a pollutant will reside in the shelf water is estimated to be on the order of one week.

In order to predict the effect of eddies on nearshore circulation a mathematical model is needed which will describe the resulting water movements. The model herein described is based on the linear combination of a background current (Florida Current), with a moving circular vortex (Florida Current eddy). The resulting flow is assumed to be two dimensional in the x - y plane, with y positive to the north and x positive to the east and the origin at a current meter. The circulation in a free circular vortex is given by Owczarek (1968) as

$$\Gamma = 2\pi \bar{r} V_\theta \qquad (2)$$

where $\bar{r}$ is the radius of the vortex and V_θ the velocity in the θ direction or direction of rotation of the vortex. The magnitude of the flow velocity induced by the vortex can be written

$$V_\theta = \frac{\Gamma}{2\pi\bar{r}} \tag{3}$$

The actual velocity as measured by a current meter $\bar{v}$ is the vector sum of the background velocity $\bar{V}$ and the velocity induced by the vortex $\bar{v}_e$

$$\bar{v} = \bar{V} + \bar{v}_e \tag{4}$$

This can be written in component form as

$$u = U + \frac{\Gamma}{2\pi\, r_e} \cdot \sin\theta \tag{5}$$

$$v = V - \frac{\Gamma}{2\pi\, r_e} \cdot \cos\theta \tag{6}$$

where r_e is the magnitude of the vector $\bar{r}_e$, positioning the center of the vortex relative to a current meter, and θ is the angle r_e makes with the x axis. The eddy position vector $\bar{r}_e$ can be written

$$\bar{r}_e = (x^2 + y^2)^{\frac{1}{2}} \tag{7}$$

where x and y are the component distances to the center of the eddy. Since the eddy is moving we can write

$$\bar{r}_e = \left[(x_o + u_{BE}\, t)^2 + (y_o + v_{BE}\, t)^2\right]^{\frac{1}{2}} \tag{8}$$

where x_o and y_o are the initial distances from the current meter to the center of the eddy, i.e. when the influence of the eddy is first beginning to affect the current meter, u_{BE} and v_{BE} are the components of the background eddy movement and t is time. Since

$$\sin\theta = \frac{y}{\bar{r}_e} \tag{9}$$

and

$$\cos\theta = \frac{x}{\bar{r}_e} \tag{10}$$

equations 5 and 6 can be rewritten as

$$u = U + \frac{\Gamma}{2\pi r_e^2} \cdot (y_o + v_{BE}t) \tag{11}$$

$$v = V - \frac{\Gamma}{2\pi r_e^2} \cdot (x_o + u_{BE}t) \tag{12}$$

Equations 11 and 12 represent a model for nearshore circulation during the passage of a Florida Current eddy. The model is based on the seven parameters U, V, u_{BE}, v_{BE}, x_o, y_o, and Γ. These parameters will describe the movement of an eddy, its position and its strength or circulation.

The seven parameters can be determined by using least square regression techniques to minimize the sum of squares

$$S_1 = \Sigma_t \left[u(P_1 \ldots P_7, t) - u(t) \right]^2 \qquad (13)$$

$$S_2 = \Sigma_t \left[v(P_1 \ldots P_7, t) - v(t) \right]^2 \qquad (14)$$

where $u(P_1 \ldots P_7, t)$ and $v(P_1 \ldots P_7, t)$ are the velocity components of the model, being a function of the 7 parameters $(P_1 \ldots P_7)$ and time (t). The u(t) and v(t) are the velocity components from the current meter data. The sum of squares S_1 and S_2 are combined to yield one set of parameters that apply to both the u and v components. Using initial estimates $(P_1^0 \ldots P_7^0)$ of the seven parameters, the difference between the minimizing parameters and the initial parameters can be solved for by regression, converging until this difference is small, thus yielding the parameters of the model. Although, the regression program has not as yet been completed, estimates of the model have been made using initial estimates of the seven parameters. Figure 57 is a computer plot of the v component computed from the data (plotted with ones) and from the model (plotted with twos) using data from current meter #2 for a 19 hour eddy on December 13, 1968. The following values were used for the initial estimates of the parameters:

U = 0.0 knots = 0.0 ft/min

V = .50 knots = 50.0 ft/min

u_{BE} = 0.0 knots = 0.0 ft/min

v_{BE} = .265 knots = 26.5 ft/min

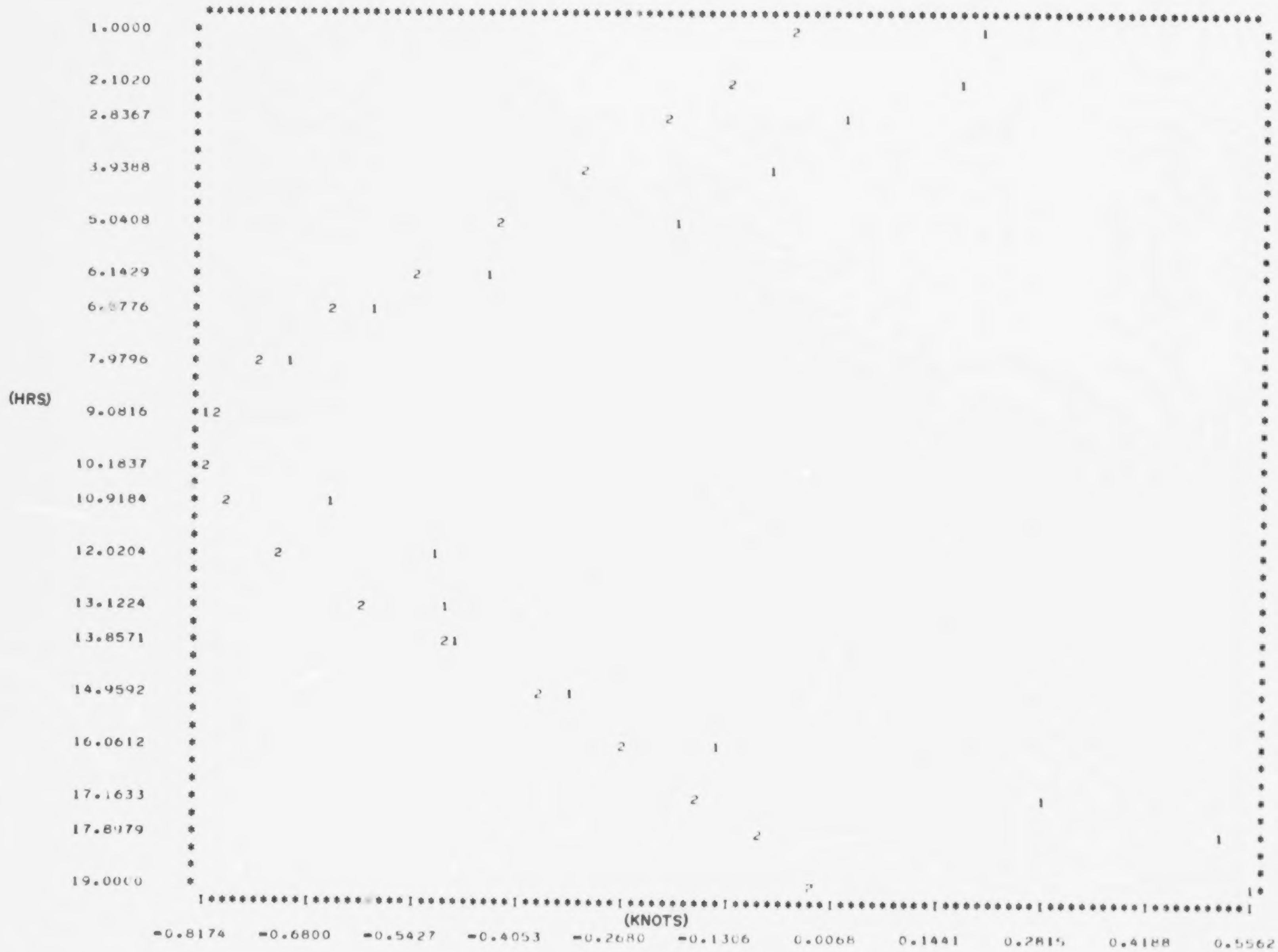
xo = 11,600.0 feet

yo = -14,830.0 feet

Γ = 9,620,000.0 feet^2/min

These parameters produce a very good fit between the model and the actual data (Figure 57). The parameters are only for the v component model (equation 12). In order to find the exact parameters that will fit both the v and u models to the data, the complete model using the least square regression program must be utilized. However, the initial estimates of the parameters are reasonably close for they were calculated from the data. These estimates show that the eddy of December 13, had a radius of approximately 6 miles and was traveling northward at about 0.26 knots. The maximum south current speed during

CHART 1



TIME V.S. V-COMPONENT - ACTUAL=1 AND MODEL=2

EDDY #2 12/13/68

Fig. 57

the 19 hour eddy is -0.82 knots and occurs when the eddy velocity, in the direction of rotation of the eddy, which is interacting with a +0.50 knot background current, is approximately 1.32 knots.

Long periods of south currents as seen in the current meter records, typically show two or more peaks of maximum south current (see Figure 55). These peaks are out of phase with the tidal currents and are far too rapid and large of a variation to be wind induced. Therefore, these peaks and the resulting currents are thought to be produced by a combination of two eddies interacting with each other and traveling northward through the shelf waters. Long periods of south currents can then be thought of as a coupling of two or more eddies moving through the area. It is a simple matter to combine eddies in the model in order to fit data with long periods of south currents and several peaks.

The passage of eddies through the study area does not display periodicity, indicating that their formation is a random process. The determination of accurate values of the eddy parameters from the model will lead to a better understanding of eddy formation in the boundary layer of not just the Florida Current, but of major ocean currents in general.

A more complete model of nearshore circulation can be developed by including in equations (11) and (12) terms for the u and v components induced by tidal and wind forces. The tidal influence is given by equation (1) and is of little importance to the resultant nearshore currents. Expressions for the wind influence need to be developed and included in the model. The wind effect does not appear to be significant to the large fluctuations that occur in the data. This is not conclusive however, because good, continuous wind data was difficult to obtain and the current meters are 25 feet beneath the surface. There may be a long term wind effect, on the order of days, that may be of importance to the model. Combining wind and tidal effects with equations (11) and (12) will yield a model for nearshore circulation that should give a very accurate fit with the actual nearshore currents.

CONCLUSIONS

The fate of waste material discharged into the nearshore receiving waters of southeast Florida is dependent upon the resultant water movements. Observed currents in the shelf waters show large variations in current speed and direction due to the extreme narrowness of the Continental Shelf and the close proximity of the Florida Current which meanders laterally up to five miles. The resultant currents are predominately in a north-south direction. Currents are to the north approximately 60% of the time and to the south about 30%. The mean current to the north is around 0.50 knots as is the mean south current. Currents in the east or west direction represent only about 10% of the observations. The mean current to the west is approximately 0.20 knots which also equals the mean east current. The average fluctuations of the observed currents ranges from 40 to 70% of the mean. The percent of this modulation due to tides is approximately 4.8% for the v component and 2.7% for the u component. Thus, tidal currents are insignificant to the resulting nearshore circulation. The periodic tidal fluctuations are dominated by the large aperiodic fluctuations produced by the meandering of the western boundary of the Florida Current and the production of Florida Current eddies which travel northward through the shelf waters. Nearshore currents show a seasonal variation in speed of 55% of the mean flow. A minimum mean north current of around 0.20 knots occurs in late January and a maximum of 0.70 knots occurs in late July.

Cyclonic spin-off eddies are produced in the western boundary region of the Florida Current and are transported northward through the southeast Florida Shelf region. The cyclonic nature of the eddies transport water from the Florida Current into the coastal waters at the start of the eddy, and carries the shelf water offshore at the end, thus the passage of an eddy can act as a flushing mechanism for the coastal waters. The duration of an eddy past one point ranges for 2 to 60 hours. Approximately 4 eddies/week travel through the nearshore waters. An eddy lasting 16 hours or greater with maximum speeds of -0.60 knots or greater will flush the shelf water. Eddies of this strength and duration occur approximately once per week. Therefore, an estimate of the residence time for coastal water is on the order of 1 week. A mathematical model for nearshore currents during the passage of an eddy is developed by combining a uniform background current (the Florida Current) with a moving circular vortex. The important eddy parameters (position of eddy, northward velocity of eddy, velocity of background current, and the eddy circulation) can be determined from the model. These parameters will aid in understanding the flushing characteristics of eddies and the dynamics of major ocean currents.

Strong temperature stratification occurs in the shelf waters during late spring and early summer. The combined effect of the stable water column and strong currents can mix discharging waste below the surface preventing the effluent from surfacing. During the remainder of the year the discharge will normally rise to the surface forming a "boil" and then move horizontally with the resultant surface current. The Pompano sewage outfall discharges into either shelf water; the western edge of the Florida Current or the western portion of an eddy. Regardless of which occurrence is taking place, the predominance of onshore winds in southeast Florida will produce a shoreward component (negative u component) in the resultant surface currents. The current meter records show that the negative u components of the current velocity can last for days with north or south currents that have an angle toward shore. The mean speed of the negative u component (west current) is -0.20 knots (±.05 knots). Therefore, effluent from the vicinity of the Pompano outfall could reach the bathing waters in 6 hours if the u component remained constant. However, as the shore is approached the current velocity will slow and become more parallel with the shoreline, decreasing the negative u component. Effluent being discharged into the nearshore waters along the southeast Florida coast will not travel indefinitely with the Gulf Stream, but will come in contact with the bathing waters at some distance and time from the point of discharge depending upon the nearshore oceanographic parameters. It is, therefore, essential to tag the effluent and follow its movement in time and space, determining simultaneously the water quality and associated oceanographic parameters.

SECTION VII

POMPANO BEACH MARINE WASTE DISPOSAL

INTRODUCTORY COMMENTS

The disposal of sewage effluent with the use of ocean outfalls was first begun in southeast Florida by Miami Beach in 1937. Since that time an increasing number of ocean fringing communities have employed outfalls. Figure 58 shows the location of ocean outfalls along the southeast Florida Coast. The particulars for each outfall are given in Table 19. The only treatment effluent undergoes for most of these outfalls is in grinding up solids into small particles and skimming off floating material. The discharge point varies from a water depth of 16 feet, located 4600 feet offshore to a depth of 90 feet, 10,000 feet offshore. At a water depth of 90 feet the bottom slope steepens to 1 foot vertical for 20 feet horizontal or greater, which is one manner of defining the edge of the Continental Shelf. It was shown in the hydrographic data that the western boundary of the Florida Current meanders laterally across this point. The outfalls of the Miami area are approximately one mile inside of the seaward edge of the Continental Shelf.

The only outfalls that have been investigated in any detail are the Pompano Beach, Delray and Hollywood outfalls. The Boca Raton outfall is under construction and should be put into operation by the end of the summer 1970. The Pompano Beach outfall has undergone intensive investigation during this study and will be the principle outfall covered in this report.

The Pompano outfall was put into operation toward the end of the 1963-1964 fiscal year. The sewage undergoes comminution to grind up solids and skimming to remove floating material. The effluent is pumped through a 30 inch diameter pipe, 7400 feet long to the discharge point in a water depth of 90 feet. Pumping is accomplished by three 2600 GPM (gallons per minute) pumps which start automatically according to the level of sewage in the holding vat. Figure 59 shows a continuous one week record of the pumping rate from the Pompano Master Lift Station. Two daily peaks are apparent, at 10:00 AM and 8:00 PM, of approximately 18×10^4 GPH (gallons per hour) or 3000 GPM. The monthly variations in the average pumping rate are given in Table 20. The values in Table 20 are based on monthly averages of daily readings taken by the City of Pompano Department of Water and Sewers. A seasonal variation of the pumping rate is clearly evident. A maximum discharge of greater than 3 MGD (million gallons per day) occurs during February and March and a minimum of about 2.5 MGD occurs in September. This variation reflects the winter population

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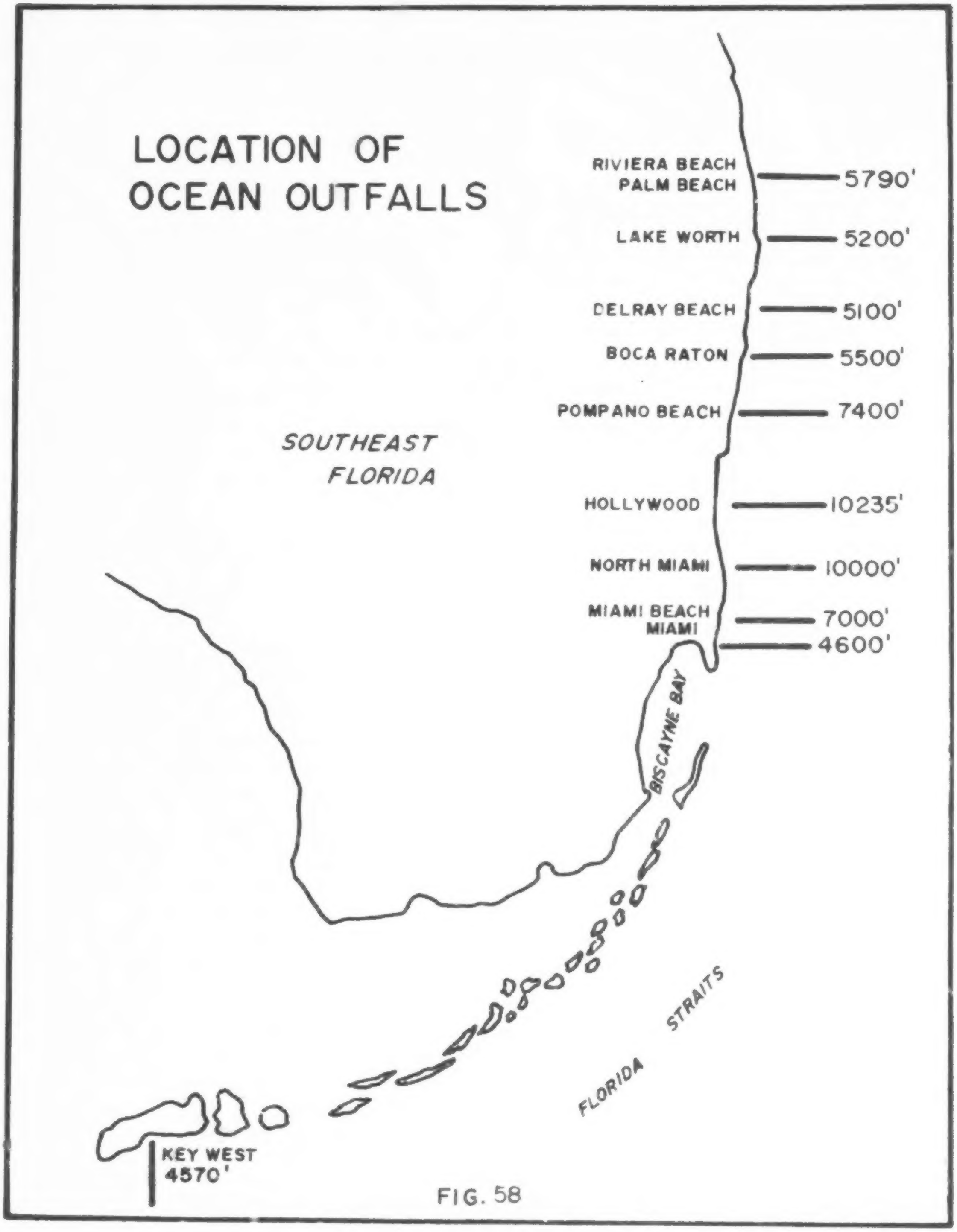

LOCATION OF OCEAN OUTFALLS
RIVIERA BEACH
PALM BEACH
5790'
LAKE WORTH
5200'
DELRAY BEACH
5100'
BOCA RATON
5500'
POMPANO BEACH
7400'
SOUTHEAST FLORIDA
HOLLYWOOD
10235'
NORTH MIAMI
10000'
MIAMI BEACH
MIAMI
7000'
4600'
BISCAYNE BAY
FLORIDA STRAITS
KEY WEST
4570'

FIG. 58

TABLE 19

OCEAN OUTFALLS ON THE SOUTHEASTERN FLORIDA COAST

LOCATION	DATE CONSTRUCTED	INSIDE DIAMETER (INCHES)	LENGTH (FEET)	WATER DEPTH AT TERMINUS (FEET)	CAPACITY (MGD) DESIGN-1968		TYPE OF TREATMENT
Miami Beach	1937	36	7,000	40	40	30	None
Key West	1952	24	4,570	33	11.5	5	None
Miami	1954	90	4,600	16	47	41	Modified Activated Sludge
Palm Beach	1956	30	5,790	90	15	6	Comminution
Lake Worth	1957	30	5,200	90	13	3	Comminution
Delray Beach	1963	30	5,100	90	15	2	Comminution
Pompano Beach	1963	30	7,400	90	17	2.7	Comminution
North Miami	1964	36	10,000	60	15	7	Primary
Boca Raton	1966	36	5,200	90	8	2.3	Uncertain
Hollywood	1968	60	10,235	90	19	11	Primary

EFFLUENT DISCHARGE FROM THE POMPANO OUTFALL

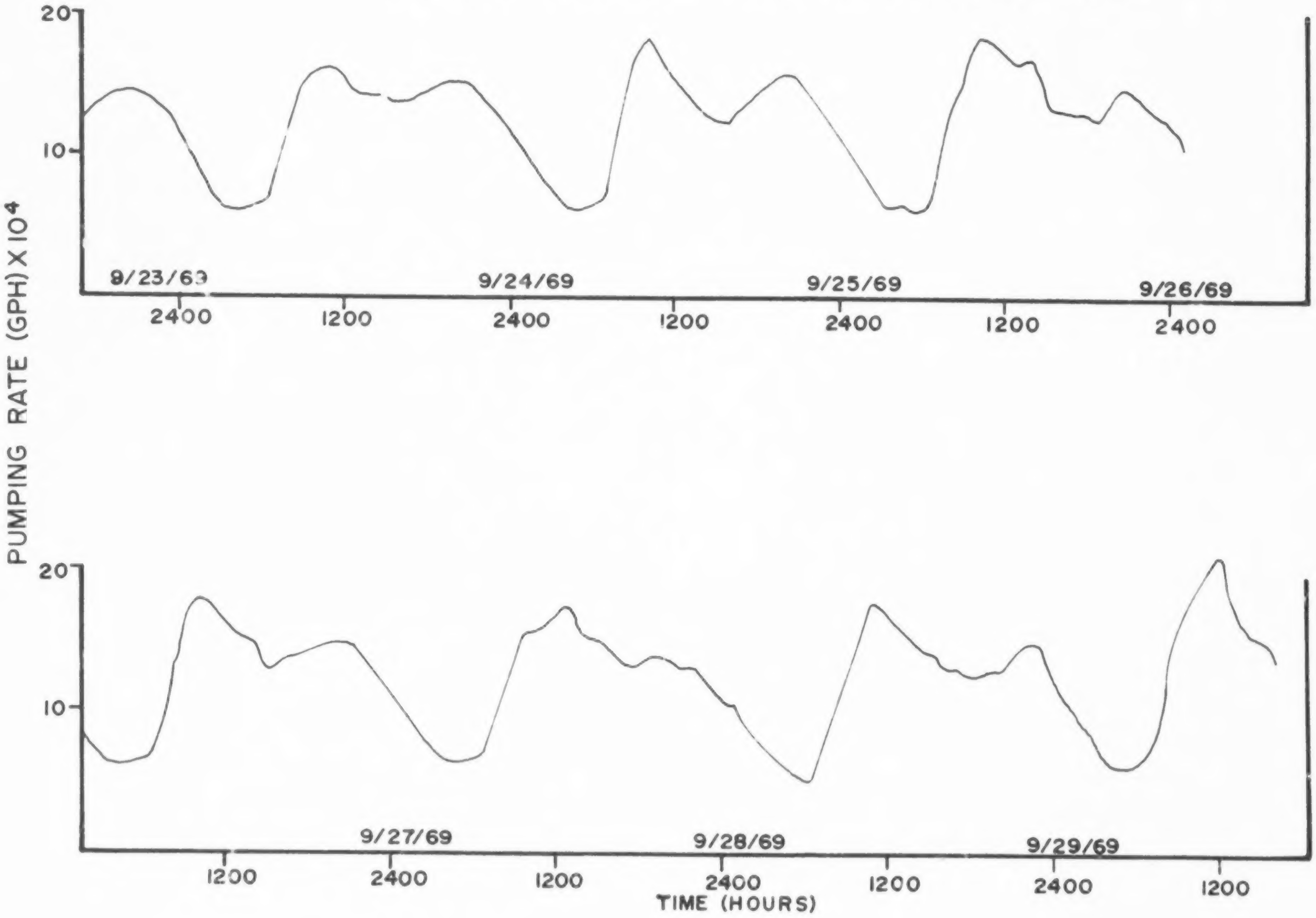


Fig. 59

TABLE 20

Monthly Averages of Pompano Outfall Discharge Rate

Month	Year	Discharge (MGD)	Temp. (^{o}F)
Sept.	1968	2.531	87
Oct.	1968	2.892	85
Nov.	1968	2.650	83
Dec.	1968	2.661	80
Jan.	1969	2.953	79
Feb.	1969	3.134	79
Mar.	1969	3.150	79
Apr.	1969	2.938	81
May	1969	2.689	83
June	1969	2.771	84
July	1969	2.930	87
Aug.	1969	2.970	88

Average 2.855

growth of south Florida.

FIELD METHODS

Sewage effluent discharged from the Pompano Beach outfall is less dense than the surrounding shelf water, therefore, rises vertically to the surface. Figure 60 is a photograph of the Pompano outfall. It shows the less dense effluent rising to the surface and heavier "sludge" being deposited as a "pile" beneath the outfall. This pile represents an organic buildup on the bottom approximately 3 feet high and stretching about 50 feet in a north-south direction and 25 feet east-west. The dimensions of this pile are constantly being changed due to variability in the pumping rate and scouring action of nearshore currents.

The rising effluent forms a "boil" in the surface above the outfall that stretches out horizontally as a "plume" in the direction of the surface current. Rhodamine-WT dye was used to tag the effluent and determine the horizontal and vertical changes in concentration. The dye was pumped continuously into the Pompano Lift Station sewage reservoir where it is homogeneously mixed with the effluent. Grab samples were taken at different locations in the Lift Station vat and at different times during the experiment. Concentration of the dye in these samples was determined in the lab by diluting the samples and reading the values from a G. K. Turner Model III fluorometer, thus, yielding values for the initial concentration in PPB (parts per billion). The initial concentrations were found to be nearly equal in space and in time during an experiment, showing the homogeneous nature of the dye-sewage mixture. Pumping dye into the lift station tags the whole effluent plume.

The concentration of dye in the boil and downstream in the plume was measured underway with the fluorometer by using a continuous flow through door and pumping water through the door at a steady rate. The intake was mounted on the transom and was adjustable from the surface down to depths of 7 feet. Plume traverses were made at right angles to the axis of the plume. Current speed and direction was determined by releasing free drifting current crosses. The temperature and salinity structure of the water column in the vicinity of the outfall was measured with a Beckman RS-5 Portable Salinometer at 10 feet intervals. Wind speed and direction and wave heights were visually estimated. Bacteria samples were taken from the outlet hose of the fluorometer at the peak dye concentration of a traverse as shown on the fluorometer readout. Bacteria samples were collected by the personnel of the Palm Beach County Health Department, iced and returned to the lab for processing. All positioning was accomplished using fixed shore located transits. Dye concentrations along a traverse were recorded on an analog strip

Reproduced from best available copy.

Fig. 20

chart recorder.

The fluorometer was calibrated for both Rhodamine-B and Rhodamine-WT. The calibration relationships between the sensitivity settings of the fluorometer and the dye concentration in PPB/chart division are presented in Table 21. There are 50 chart divisions on the strip chart, therefore, the fluorometer is capable of detecting dye concentrations over a 1500 PPB range. The range can be greatly extended by diluting the sample.

Pompano fluorometry experiments were begun in earnest during the last week of August, 1969. Since that time 19 experiments have been conducted, amounting to approximately one experiment per week, weather permitting. A physical description of these experiments is given in Table 22. Initial dilution is the dilution of the effluent due to rising from the outfall pipe to the surface. The initial dilutions of Nov. 3 and Nov. 10 are questionable. On Nov. 3 the concentration measured in the boil was much too low, due to boil movement in a strong current, giving an erroneous value for the initial dilution. Disregarding these two measurements, initial dilutions range from about 70:1 to about 250:1. Downstream dilutions are due to the changes in dye concentration from the boil to some distance downstream in the plume, they are typically an order of magnitude less than initial dilutions. Total dilutions are the overall dilution for the experiment, from the initial concentration to the peak concentration at the furthest point measured downstream from the boil. Disregarding experiments of Jan. 21 and Jan. 26 which were slugs of dye injected in the lift station, total dilution ranges from 1000:1 to 6000:1. This dilution is dependent on the amount of time and distance from the boil. Dye slug experiments of Jan. 21 and Jan. 26 were conducted in order to tag the effluent for longer time periods. These runs will not be reported at this time as the analysis that follows was set up for continuous source experiments.

Field experiments typically lasted about four hours. After this time the sampling boat would be a distance from the boil where dye concentrations were too low to be measured with the fluorometer. The field experiments usually began by starting the dye pump at 0700 hours. There was a time delay of nearly 90 minutes before the dye would surface in the boil. Then after waiting another 90 minutes for the dye plume to reach a "quasi-steady state" the measurement program would begin.

WASTE DISPOSAL FROM AN OCEAN OUTFALL

MODELS

In the literature most of the effort to understand the spreading of a plume from an outfall has centered around a diffusion

TABLE 21

FLUOROMETER CALIBRATION

	1x	3x	10x	30x
Rho-B (PPB/chart div.)	1.54	0.56	0.19	0.048
Rho-WT (PPB/chart div.)	3.50	0.77	0.31	0.071

TABLE 22

FLUOROMETRY EXPERIMENTS

Date	Discharge (GPM)	Initial Conc. (PPB)	Initial Dil.	Down Stream Distance (Ft)	Down Stream Dil.	Total Dil.	Current Speed (Knots)	Wind Speed (Knots)	Wind Dir.
8/26/69	3403	1278	87/1	12,900	61/1	5325/1	0.32	9	E
8/27/69	2822	1509	73/1	4,500	54/1	3930/1	0.43	14	E
8/28/69	3423	1078	80/1	4,500	14/1	1135/1	0.55	6	NNE
9/16/69				7,500	5/1		0.31	4	SE
9/29/69	2203	1988	225/1	13,800	5/1	1035/1	0.75	4	E
10/15/69	5013	934	129/1	6,100	23/1	3030/1	0.28	8	SE
11/3/69		308	20/1	5,600	61/1	1232/1	0.55	8	N
11/10/69	4100	1085	1154/1	11,100	1.2/1	1391/1	1.00	8	NW
11/24/69	1925	1820	100/1	3,200	11/1	1067/1	0.42	17	E
12/1/69	2542	2205	179/1	12,780	17/1	3106/1	0.80	18	NW
12/8/69	1780	2030	187/1	3,900	22/1	4060/1	0.10	17	N
12/15/69	2740	2117	165/1	6,090	61/1	10,081/1	0.35	6	W
1/5/70 AM	2370	1190	147/1	2,450	16/1	2380/1	0.28	20	E

TABLE 22 continued

Date	Distance (GPM)	Initial Conc. (PPB)	Initial Dil.	Down Stream Distance (Ft)	Down Stream Dil.	Total Dil.	Current Speed (Knots)	Wind Speed (Knots)	Wind Dir.
1/5/70 PM	2370	1190	129/1	5,550	18/1	2380/1	0.28	20	E
1/12/70	3100	910	259/1	11,550	25/1	6500/1	0.85	9	SW
1/19/70	4430	262	258/1	1,400	3/1	750/1	0.60	3	SW
1/21/70		16,130	192/1	9,200	400/1	76,800/1	0.60	16	NNW
1/26/70		32,260	176/1	21,400	108/1	19,000/1	0.70	6	S
2/9/70	1680	1575	216/1	9,400	26/1	5620/1	0.40	6	W

model.

The argument runs as follows: We have a dye concentration at every point in space and time, $\rho(x,y,z,t)$. Central to the diffusion model is the assumption that the contaminant will flow from regions of higher concentration to regions of lower concentration; in other words there is a concentration current density $\bar{j}(x,y,z,t)$ which is

$$\bar{j}(x,y,z,t) = -k\bar{\nabla}\bar{\rho}(x,y,z,t) + \rho\bar{v}. \qquad (1)$$

The coordinate system is arranged so that x is the downstream direction, y is the cross stream direction and z is vertical. The first term in this expression is a diffusion term which says that the concentration "flows" in the direction of decreasing concentration, k is the diffusion coefficient. The second term is an advective term which accounts for the concentration being translated by a background current ($\bar{V}$).

The fact that the total amount of contaminate is conserved leads to an equation of continuity which is

$$\nabla \cdot \bar{j} = \partial\rho/\partial t. \qquad (2)$$

this equation is simply an expression of the idea that the amount of efflux from a differential volume ($\nabla \cdot \bar{j}$) is equal to the decrease of contaminate with that volume ($\partial\rho/\partial t$).

The equation which must be solved is

$$-k\nabla^2\rho - (\nabla k - \bar{v}) \cdot \nabla\rho + \rho\nabla \cdot \bar{v} = \partial\rho/\partial t. \qquad (3)$$

Some work has been done on this equation in full generality, however, we find it more instructive to consider only certain limits which allow a much simpler discussion.

1. The Diffusion Limit: One assumes here that
   a) We seek a time-independent solution hence
      $\partial\rho/\partial t = 0$
   b) The background velocity is everywhere constant $\therefore \nabla \cdot \bar{v} = 0$
   c) k, is constant in space and time, thus
      $\nabla k = 0$

this leaves an equation

$$-\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right)\rho(x,y,z) + \frac{|U|}{K} \cdot \frac{\partial\rho}{\partial x} = 0 \qquad (4)$$

provided that we assume the constant current speed is in the x direction (in the direction of the current) which we may do without loss of generality. One can solve this equation without further approximation, but again it is more instructive to neglect $\frac{\partial^2\rho}{\partial x^2}$ in comparison to $\frac{U}{K}\frac{\partial\rho}{\partial x}$, that is to not worry about downstream diffusion.

Finally, then, in this simplest diffusion model, we have the standard equation for two dimensional diffusion with the time being replaced by the downstream distance divided by the current velocity.

If we assume the downstream size of the plume is very large compared to the initial boil we are justified in using a point-source solution to this equation which is

$$\rho(x,y,z) = \frac{R}{\pi U \sigma_y(x)\sigma_z(x)}\, e^{-\frac{y^2}{2\sigma_y^2(x)}}\, e^{-\frac{z^2}{2\sigma_z^2(x)}} \qquad (5)$$

$$\sigma_y^2(x) = \sigma_z^2(x) = \frac{kx}{U} \qquad (6)$$

σ_y, σ_z = standard deviation in the y and z directions.
R = pumping rate of the contaminate.

Although this model is not particularly successful in describing the dispersion of contaminate it does provide a motivation for the way in which we have analyzed our data.

In order to give some shape to our data we have "kept score" by saying that we assume a form for ρ consistent with equation (5), but we leave $\sigma_y(x)$ and $\sigma_z(x)$ to be determined by experiment rather than both of them being determined by the downstream distance.

2. The Stream Line Limit: In this limit we assume
   a) We seek a time-independent solution hence $\partial\rho/\partial t = 0$
   b) $k(r) = 0$, thus there is no diffusion.

Under these assumptions

$$\bar{v} \cdot \nabla\rho = 0 \qquad (7)$$

This equation means that the concentration is constant along a stream line. If the background fluid is incompressible and is in irrotational flow, then

$$\bar{v} = \nabla\Phi \qquad (8)$$

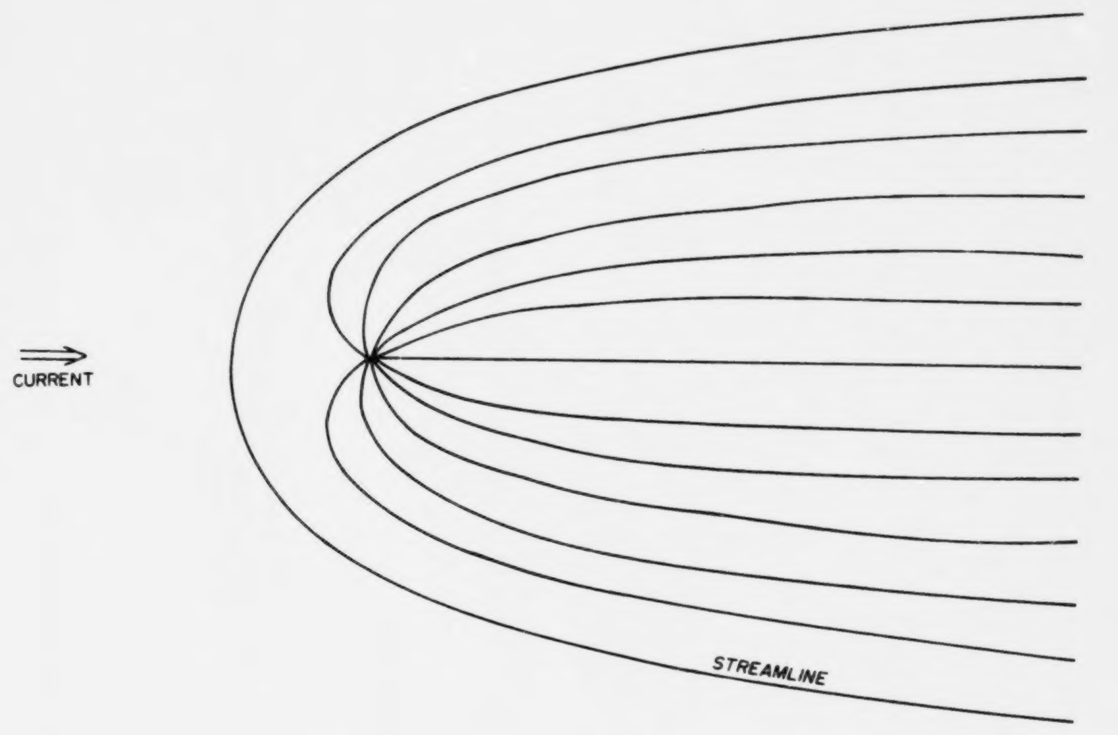
and

$$\nabla^2\Phi = 0 \qquad (9)$$

Φ = velocity potential

Figure 61 is a sketch of a two-dimensional plume generated by a point-source. Note the following features of this plume.

a) There is no concentration dilution down-stream.
b) The plume approaches a fixed width, and does not continue to spread.


CURRENT
STREAMLINE

STREAMLINE MODEL OUTFALL PLUME

Fig. 61

Both of these facts are contrary to our experimental data. We will, however, make use of the stream line plume in attempts to extrapolate our data to other situations.

DATA ANALYSIS

As previously indicated the diffusion model provides the basis of our analysis.

The data collected include:

a) A series of transit marks from fixed shore location.
b) The strip-chart fluorometer record.
c) Various physical data: current velocity, wind velocity, grab sample dye concentrations from the lift station reservoir.

The first step in the analysis is the graphical reduction of the transit marks from each station which are plotted by hand on a map of scale 1" = 300'. From this map the length of the transect and the distance of the mid point of the transect are read directly. The Rustrak data is digitized by reading the strip chart in intervals of .1" and taking an estimated average value for the concentration over that interval.

As previously indicated the diffusion model provides the basis for our analysis. For each transect we assume that

$$\rho(x,y,z) = \frac{R}{\pi U\sigma_y(x)\sigma_z(x)} e^{-(y - y_o)^2/2\sigma_y^2(x)} e^{-(z)^2/2\sigma_z^2(x)} \quad (10)$$

We calculate the parameters $\sigma_y (x)$, $\sigma_z(x)$ and y_o in two ways:

1) Sample Fit Analysis

In this method of analysis we calculate the mean position of the concentration, the standard deviations of the concentration about the mean and the amount of dye swept out in each transect. If we assume uniform boat speed we can divide the transect into the same number of intervals as the analog record.

Let

Δy = The length of each interval.

$\rho(s)$ = The concentration at the center of the s^{th} interval.

μ = Distance to the mean of the concentration along the transect.

σ = Standard deviation of the concentration about the mean.

$$\mu = \Delta y \sum_{s=1}^{n} \rho_s (s-\tfrac{1}{2}) / \sum_{s=1}^{n} \rho_s \qquad (11)$$

$$\sigma = \left(\Delta y^2 \sum_{s=1}^{n} (s-\tfrac{1}{2})^2 \rho_s / \sum_{s=1}^{n} \rho_s - \mu^2\right)^{\frac{1}{2}} \qquad (12)$$

If we assume that the shape of the concentration profile is Gaussian we can calculate the peak concentration.

If we assume that P = peak value of concentration,

$$P = \Delta y \sum_{s=1}^{n} \rho(s) / \sqrt{2\pi}\sigma_y \qquad (13)$$

and if we assume that the form given previously for $P(x,y,z)$, we can then calculate the depth of the contaminate distribution.

$$\sigma_z = R/\sqrt{\pi/2} \cdot \Delta y \sum_{s=1}^{n} \rho(s) \cdot U \qquad (14)$$

where R = dye release rate (cu. ft/hr)
and U = current speed (ft/hr)

These things are computed for each transect of every run and are listed in the printout of results.

2) Gaussian Fit Analysis

This type of analysis tries to take into account the experimental problem which arises due to the sensitivity of the fluorometer. It is often observed that the fluorometer does not record the presence of dye when the dye is apparent to the naked eye. This is due to the fact that it is not desirable to switch fluorometer sensitivity in the middle of a transect. When the fluorometer is set on its highest sensitivity the dye concentration recorded will be only at the higher values along the transect. That is, we only see the peak.

Under these circumstances the sample fit method will consistently underestimate the width of the plume.

We have attempted to correct this observational bias by making a Gaussian fit to the observed concentration. We fit the observed concentration data with a Gaussian shape containing three parameters. For fixed depth z, and fixed downstream distance we have

$$\rho(y) = P e^{-(y-y_0)^2/2\sigma_y^2} \qquad (15)$$

P = peak value
y_0 = mean value
σ_y = cross-stream standard deviation

In making a least-squares fit with a regression function such as this it is better to fit the logarithm of the data to the logarithm of the regression function. Thus at the s^th interval

$$\ln \rho(s) = Y(s) \qquad (16)$$

$$\ln \rho(y_s) = \ln P - \frac{1}{2\sigma_y^2} (y_s - y_0)^2, \qquad (17)$$

and in this form we determine the Gaussian parameters from a least square fit of a second degree polynomial to the logarithm of the concentration at every interval. By this means we determine a peak concentration, a mean value and a standard deviation for the concentration profile at every transect.

The logarithm of the cross plume standard deviation computed by both the Gaussian fit analysis and the sample fit analysis is plotted (abscissa) against the logarithm of the x distance (ordinate) of each transect downstream from the boil (Figures 62-97). These plots were performed on the IBM 360 computer at Florida Atlantic University. The "ones" are the (computed) standard deviations. A linear regression function was fitted through these values using least square techniques and is plotted as "twos". The date of each run is shown at the top of the drawing as year-month-day. A linear regression function of the form

$$\Sigma_y = (B1)X + B2 \qquad (18)$$

was used to fit the data.

where $\Sigma_y = \log_e \sigma_y$
$X = \log_e x$

The coefficients B1 and B2 were determined from the fit and are shown in the lower righthand corner of each plot. These plots show a good comparison between the two techniques. Equation (18) can be used to predict the spread of the plume with downstream distance. Using

$\Sigma_y = \log_e \sigma_y$

$X = \log_e x$

we can write equation (18) as:

$$\sigma_y = \text{antilog}\ (B2)\ x^{B1} \qquad (19)$$

The spread of the plume depends on the power B1. Table 23 lists the values of B1 computed by the two techniques. Table 23 also shows that the agreement between the two techniques becomes better as the amount of data increases (# of transects). The negative values of experiments on 11/10, 12/8 and the low values of 11/24 and 1/5 AM are the result

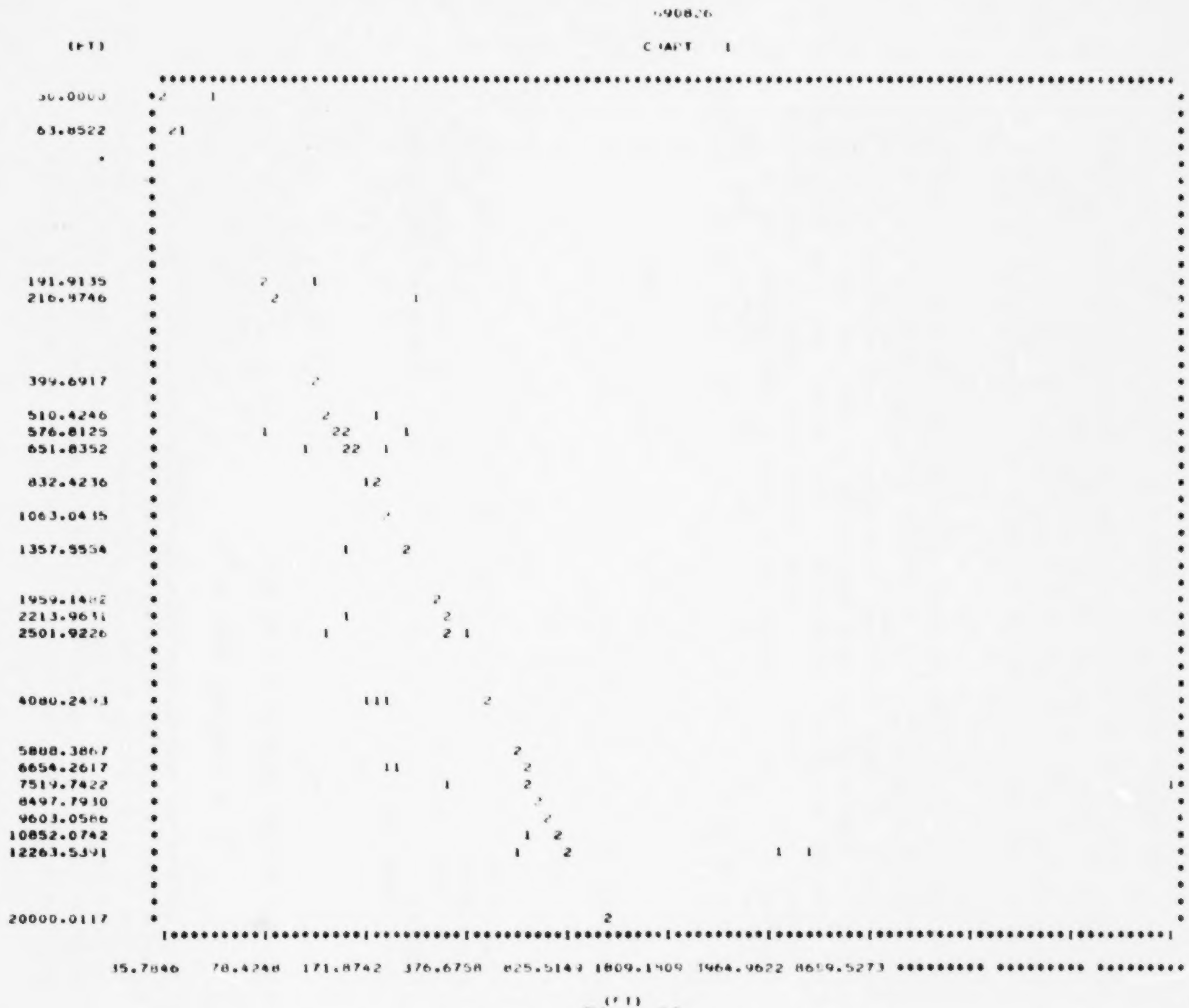


Fig. 62
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.37714
B2= 1.11975

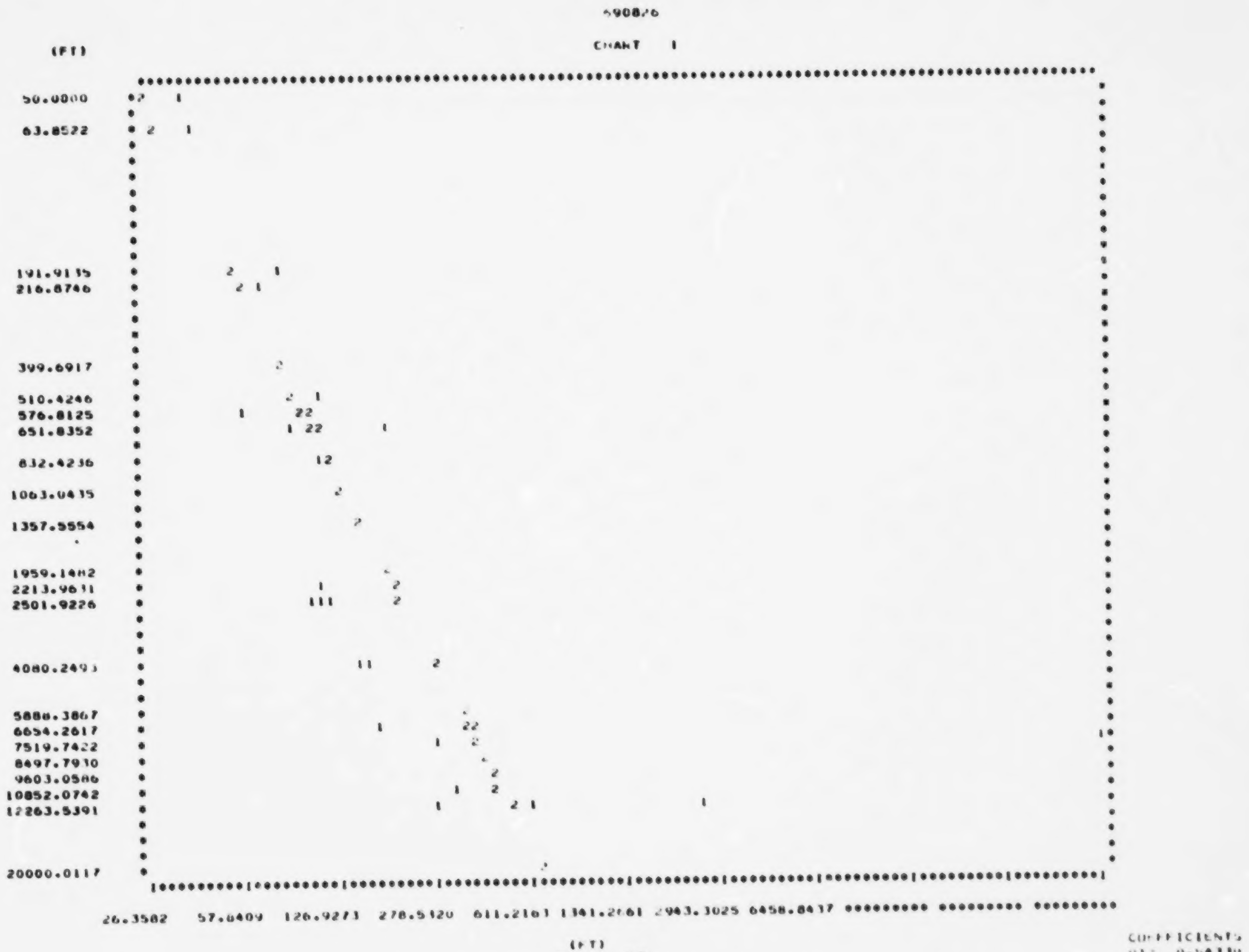


Fig. 63
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

```
GAUSSIAN RESIDUE(PPM) AT EACH INTERVAL
  0.01    0.04    0.03  -0.05    0.05  -0.02  -0.19  -0.07  -0.01
  0.14    0.16    0.10   0.02  -0.04  -0.05  -0.01   0.01
                                                       6908.7
```

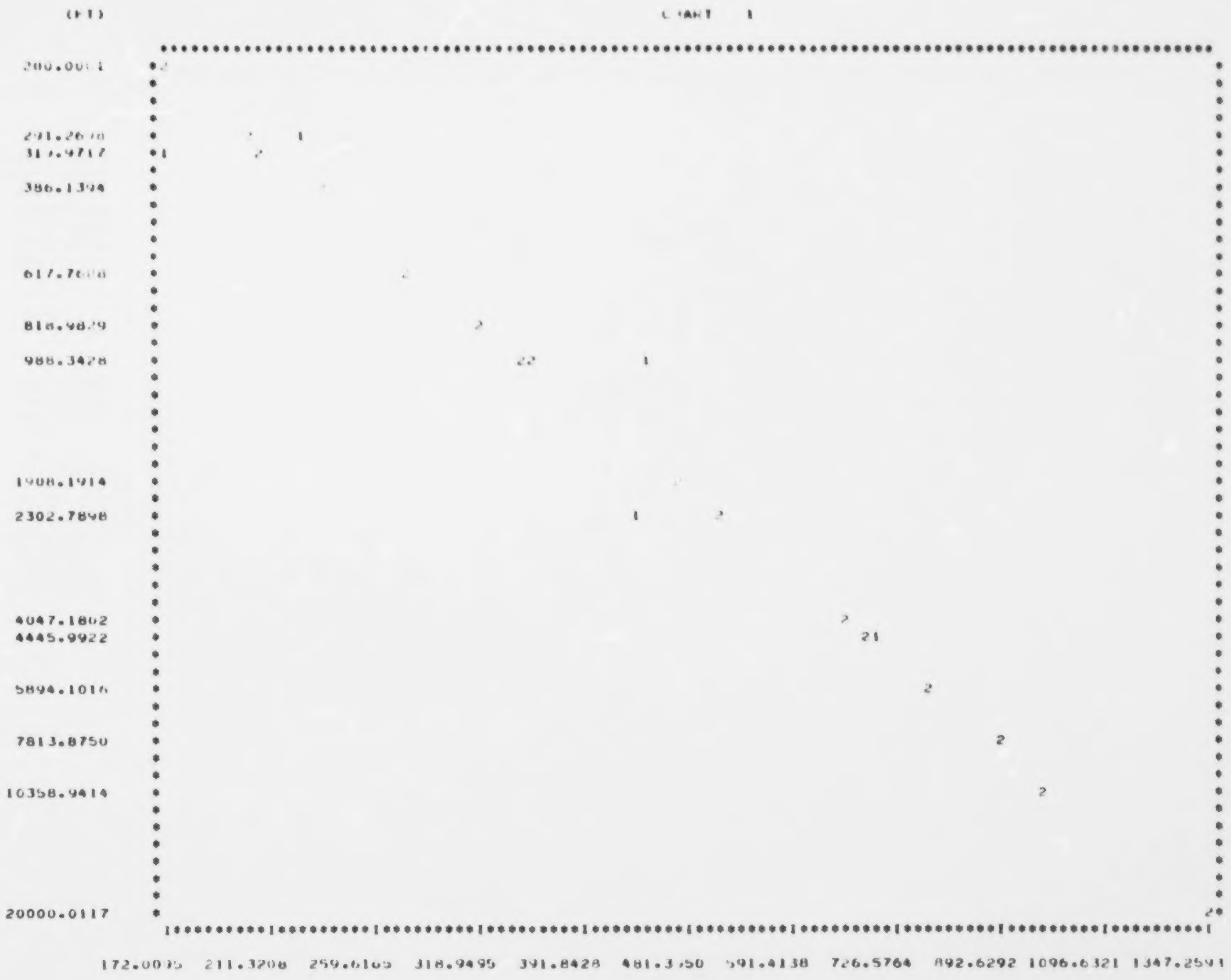


Fig. 64

DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

```
COEFFICIENTS
B1=  0.44695
B2=  2.77947
```

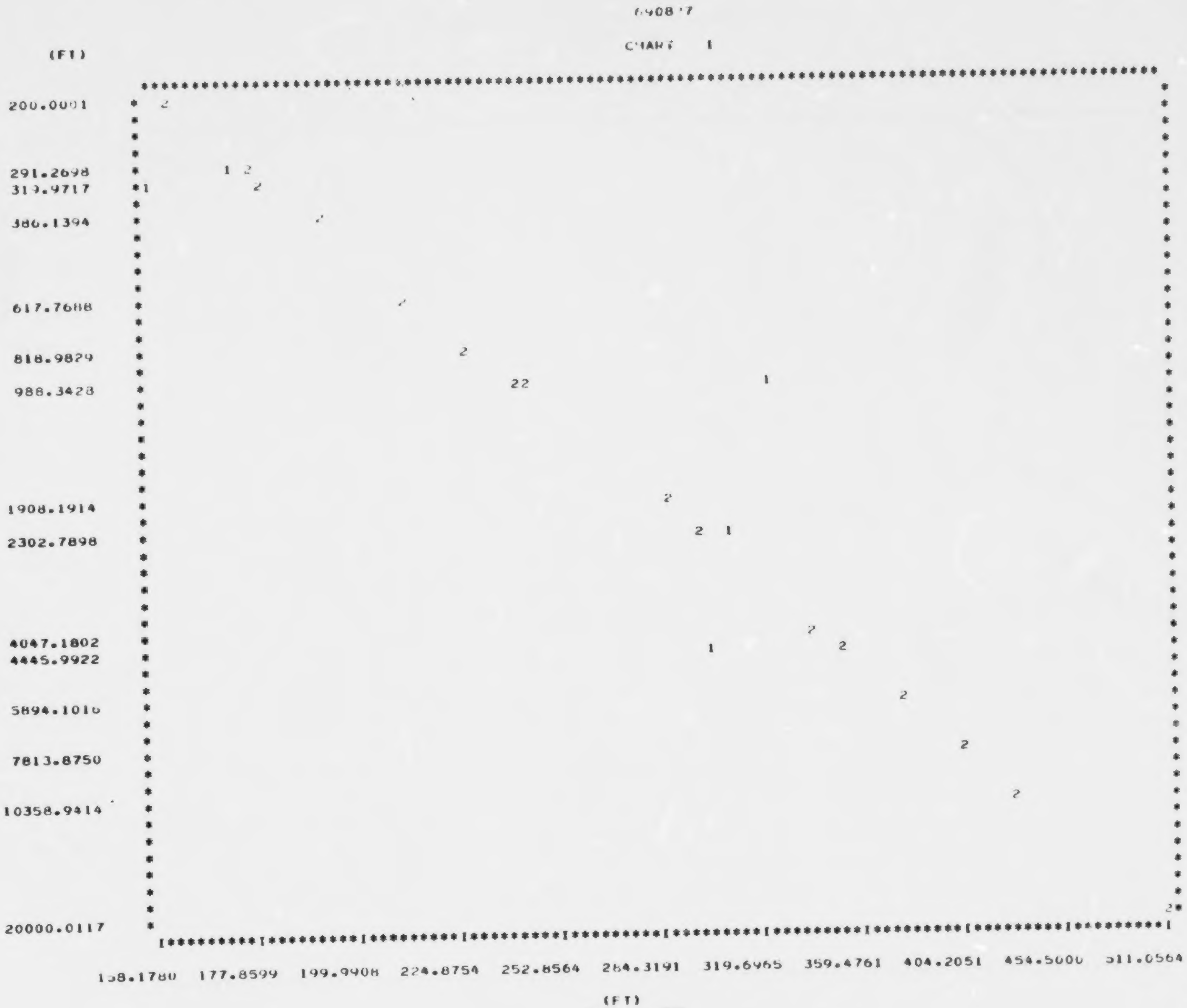


Fig. 65
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1- 0.24854
B2= 3.77509

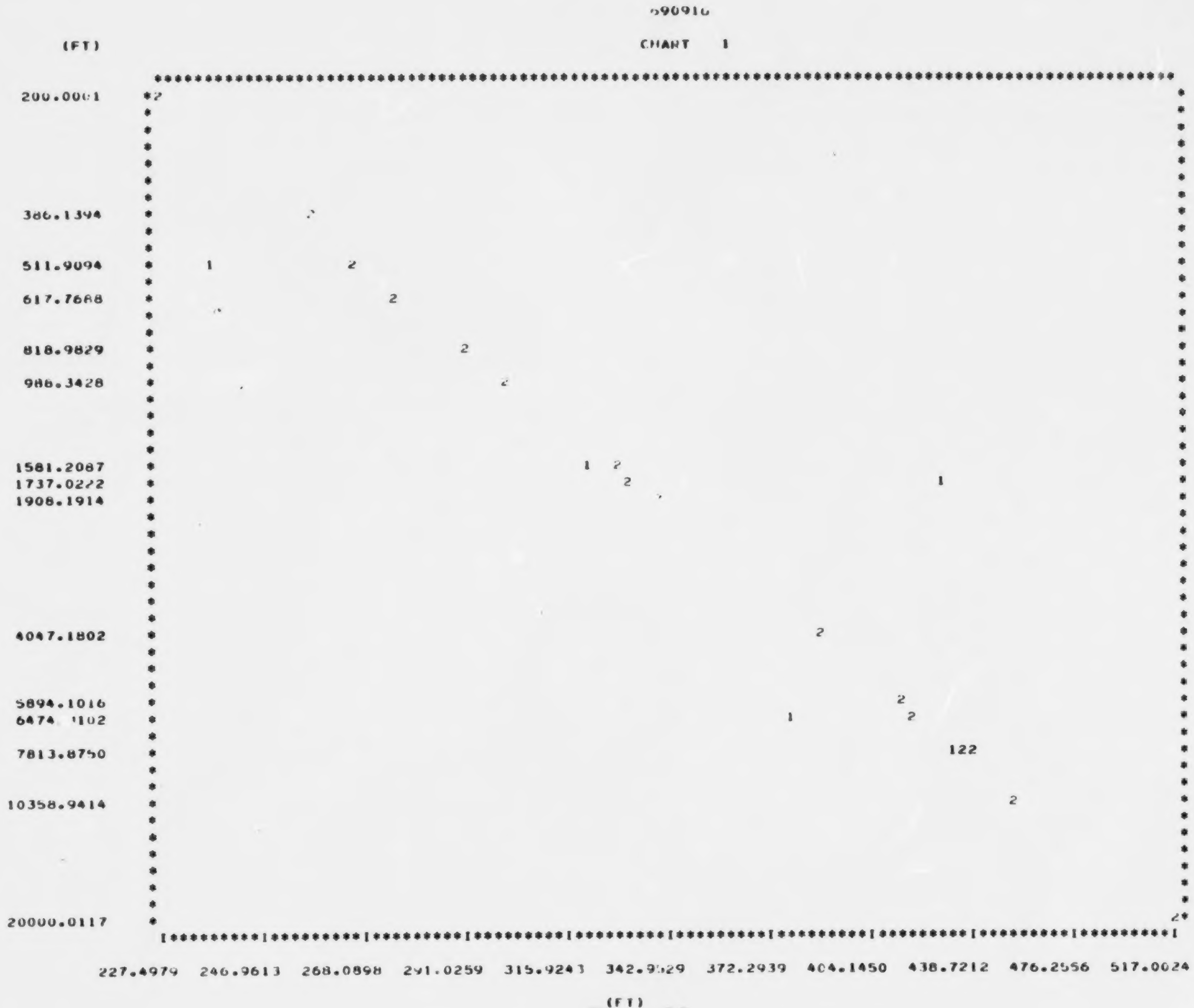


Fig. 66
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.17826
B2= 4.48268

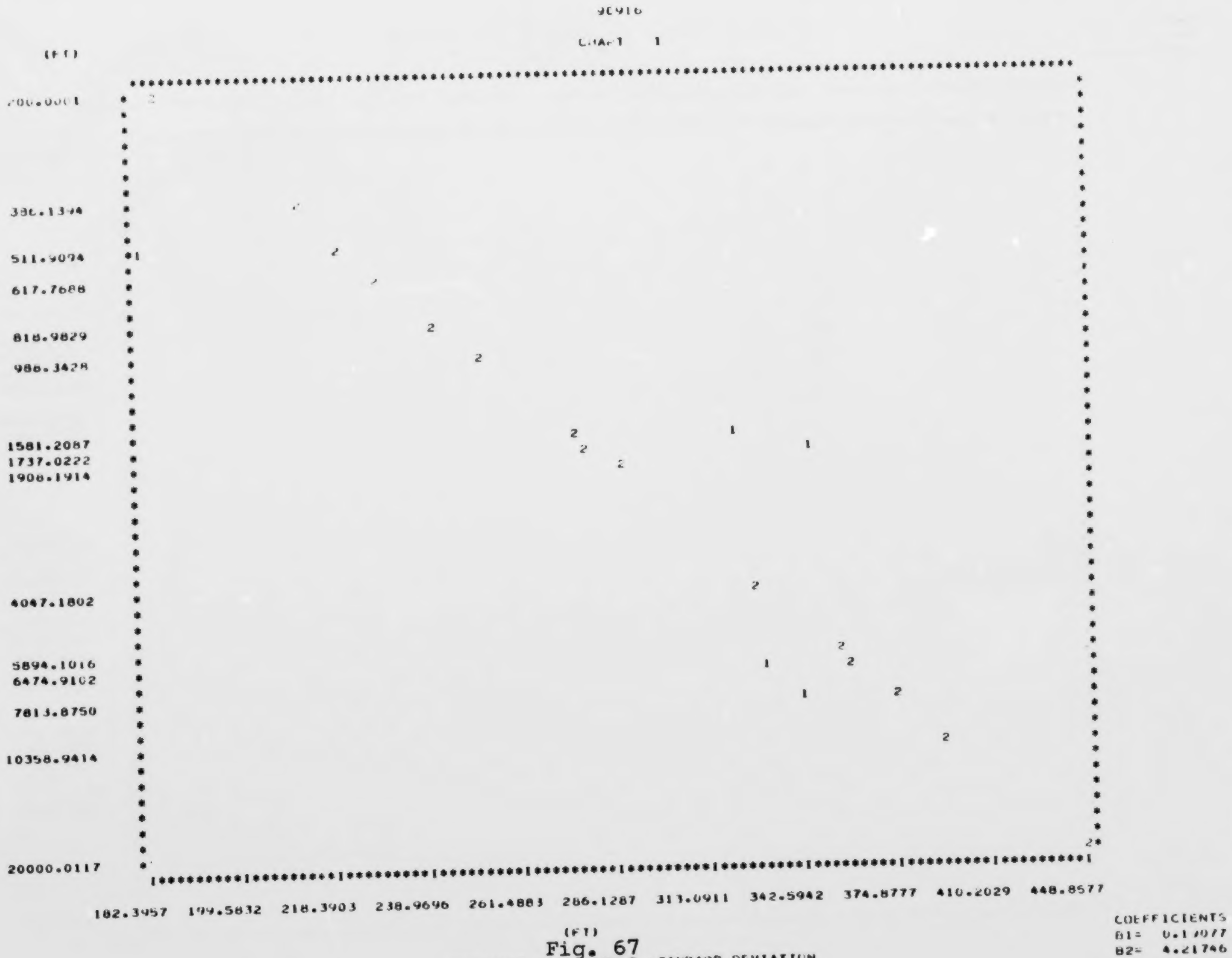


Fig. 67
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

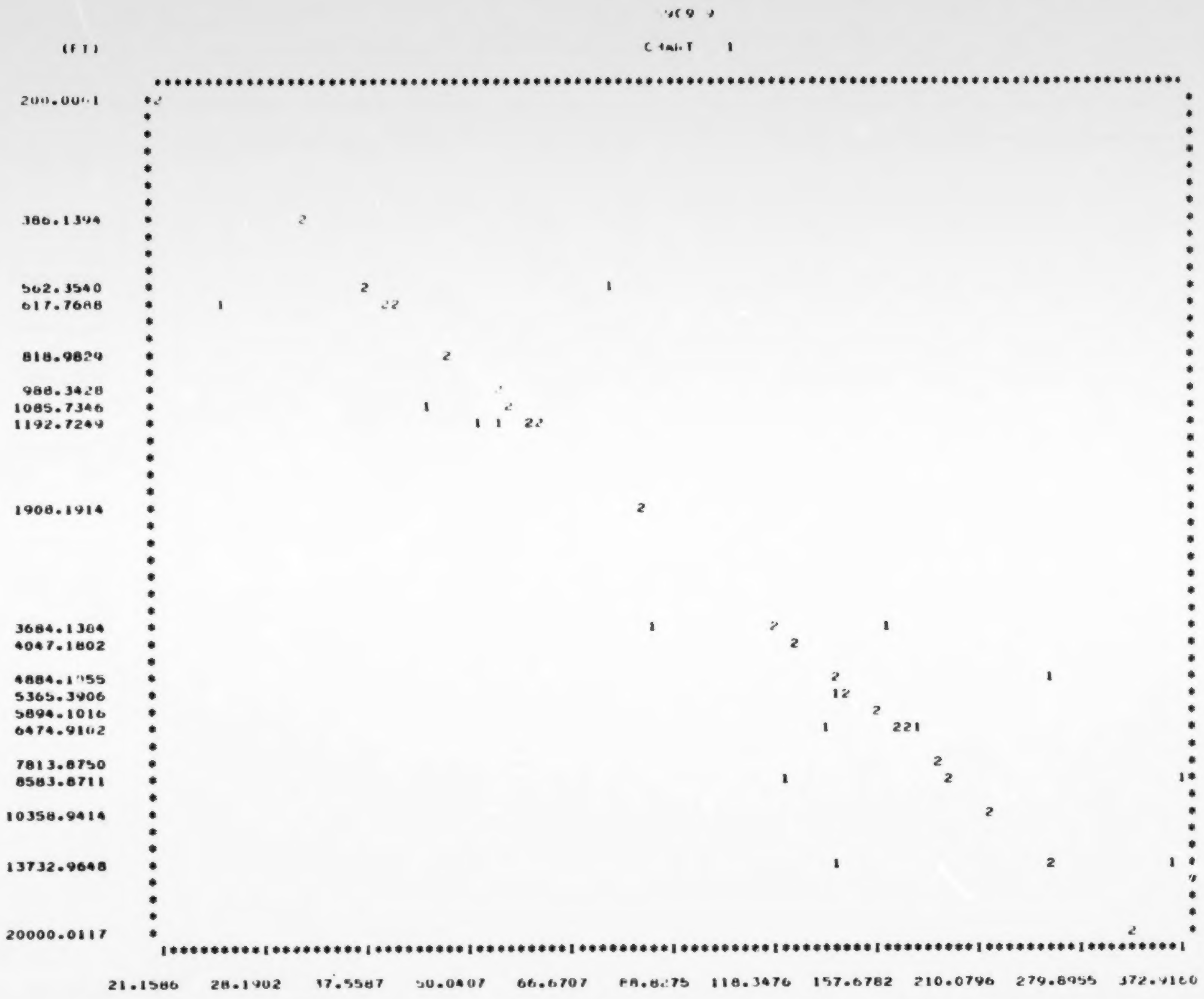


Fig. 68
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.59544
B2= -0.10278

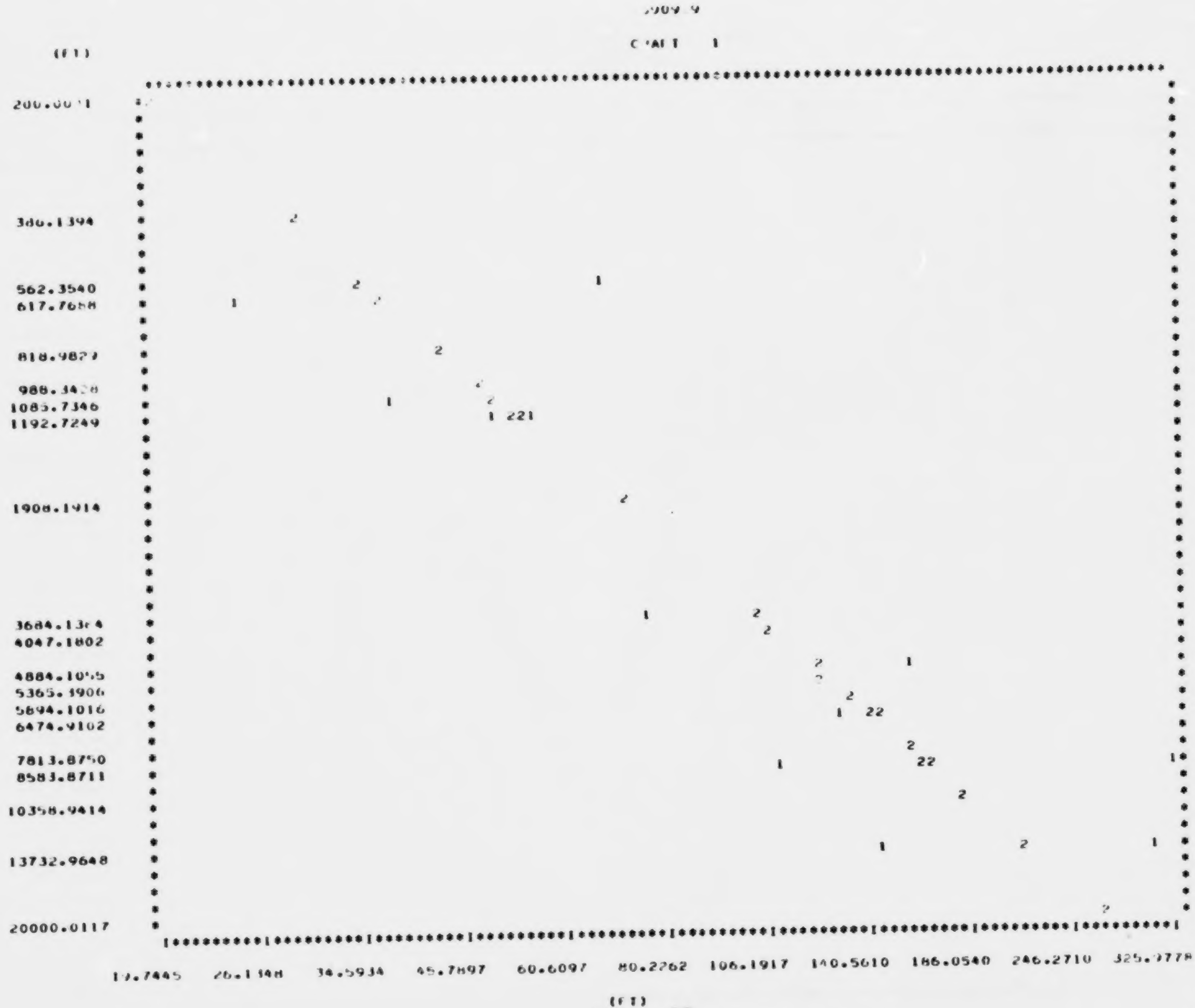


Fig. 69
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.56749
B2= -0.02350

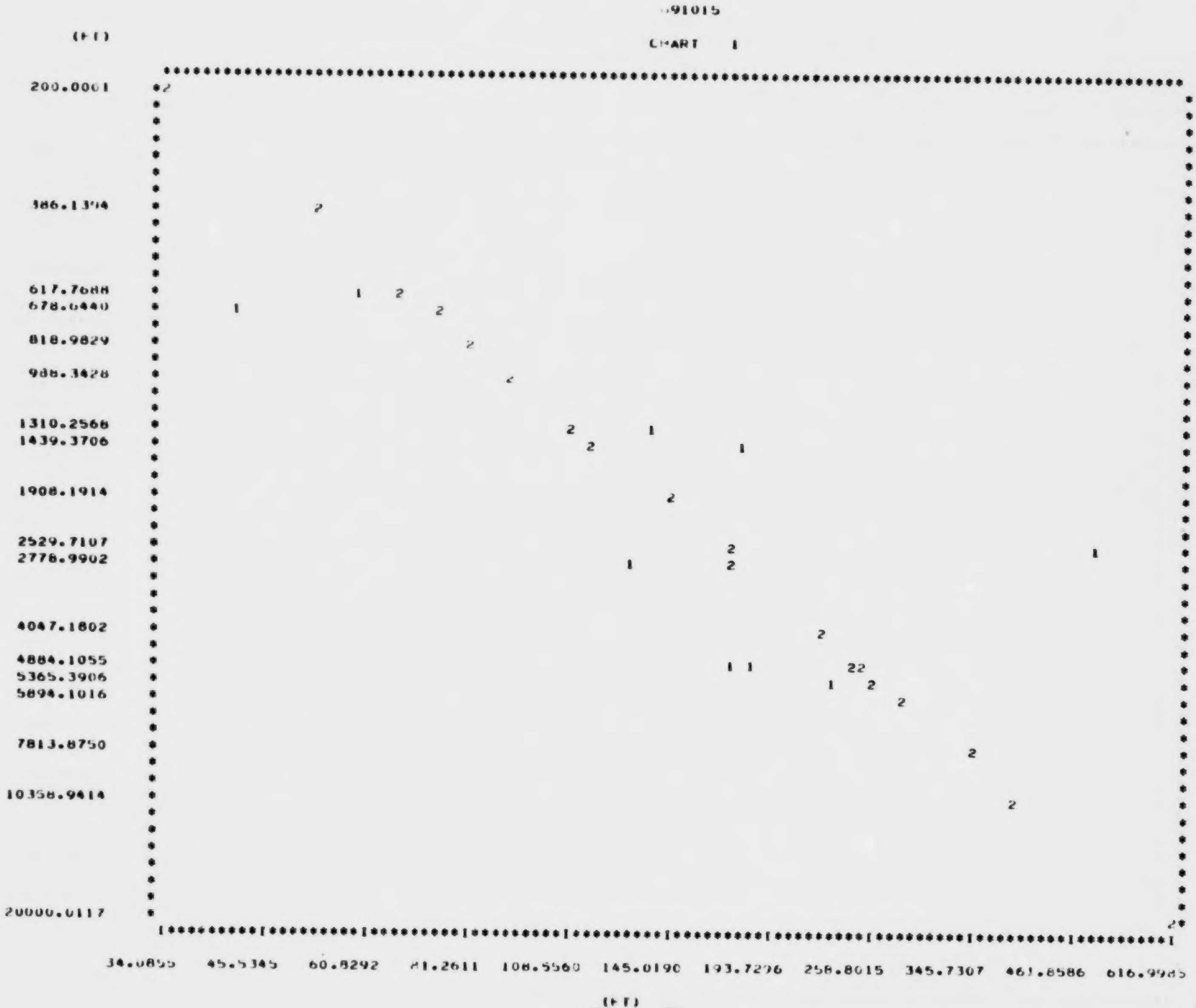


Fig. 70
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.62886
B2= 0.19699

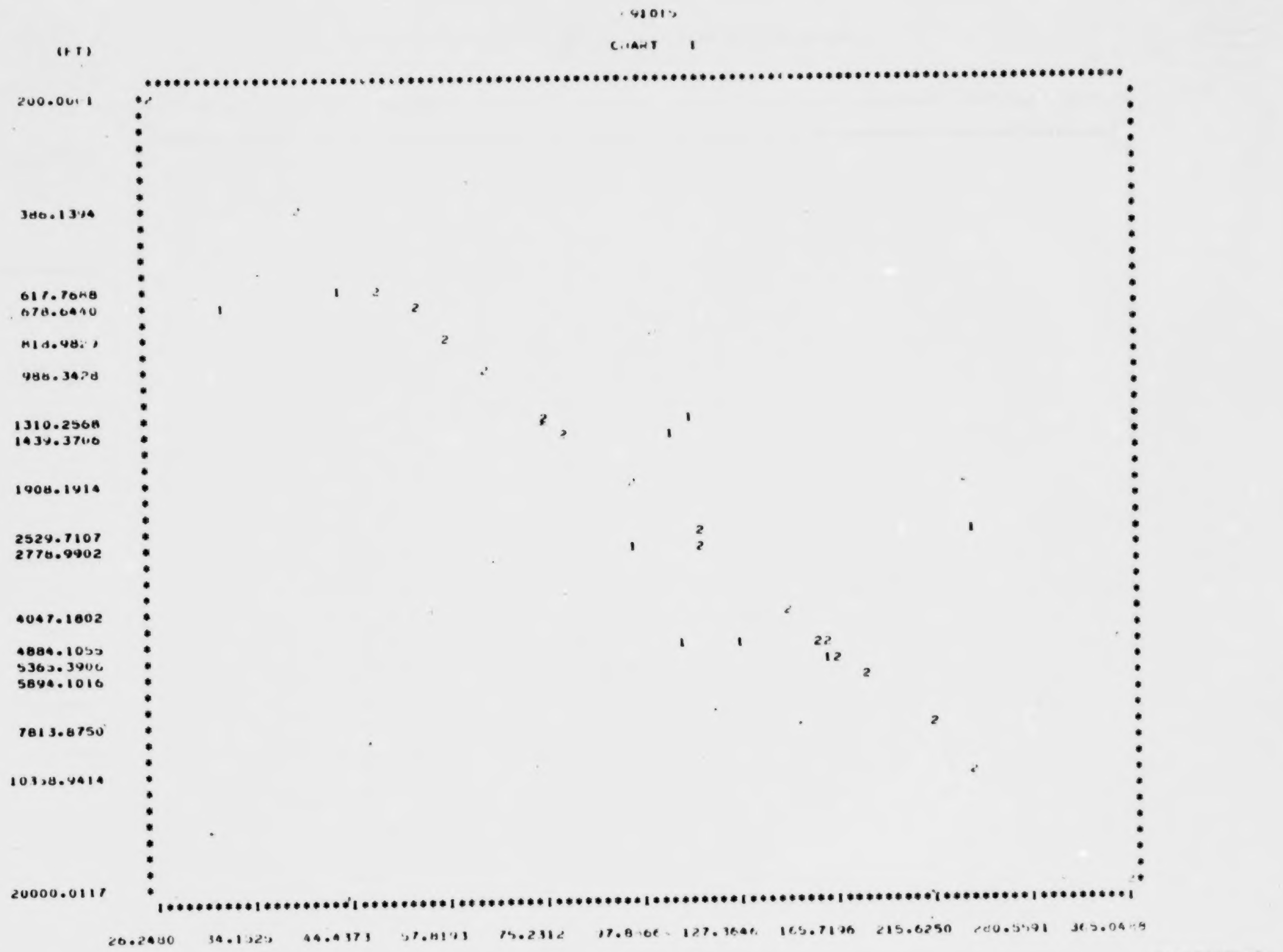


Fig. 71
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

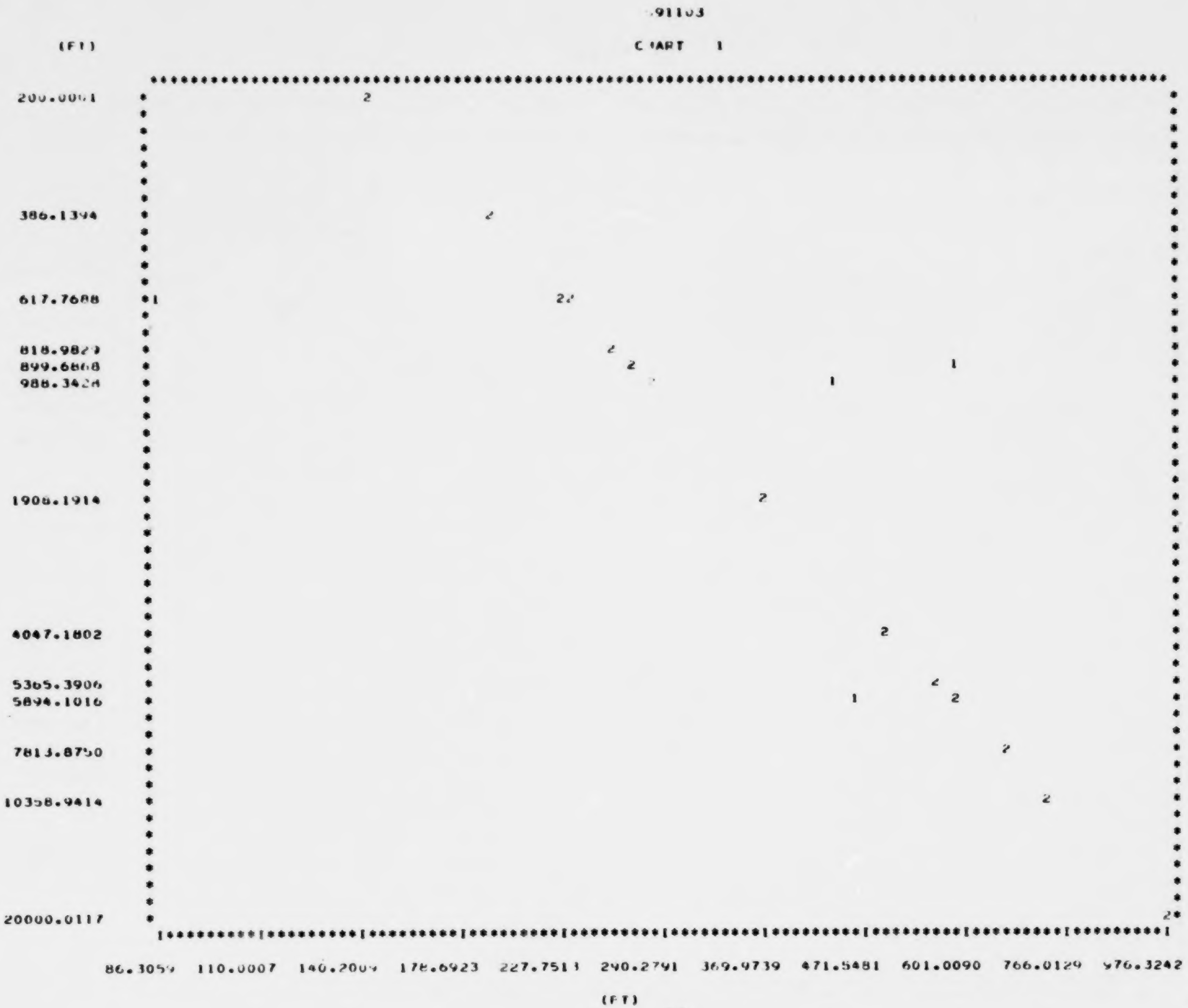
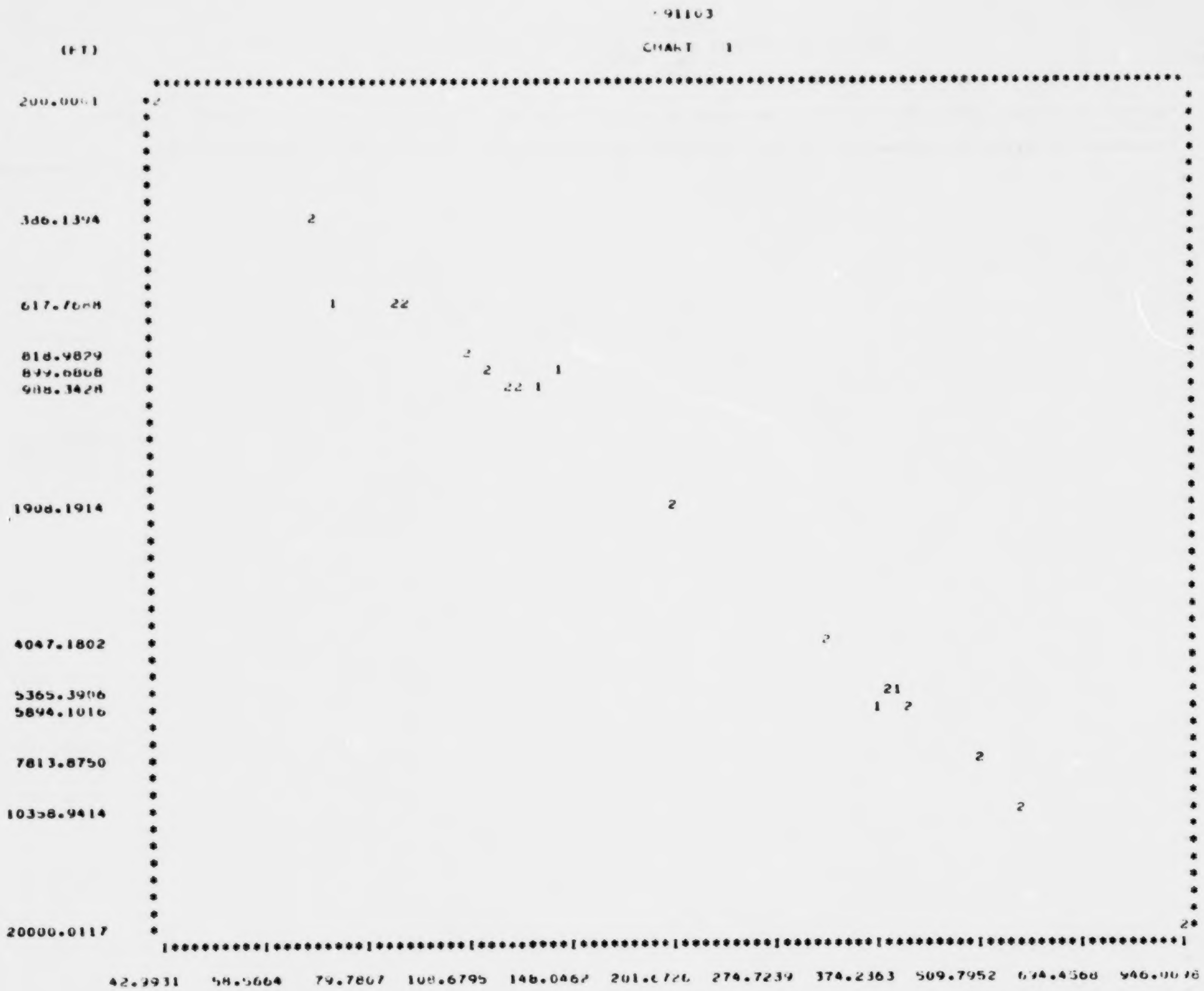


Fig. 72
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.41117
B2= 2.81180



(FT)

Fig. 73

DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.57125
B2= 0.20455

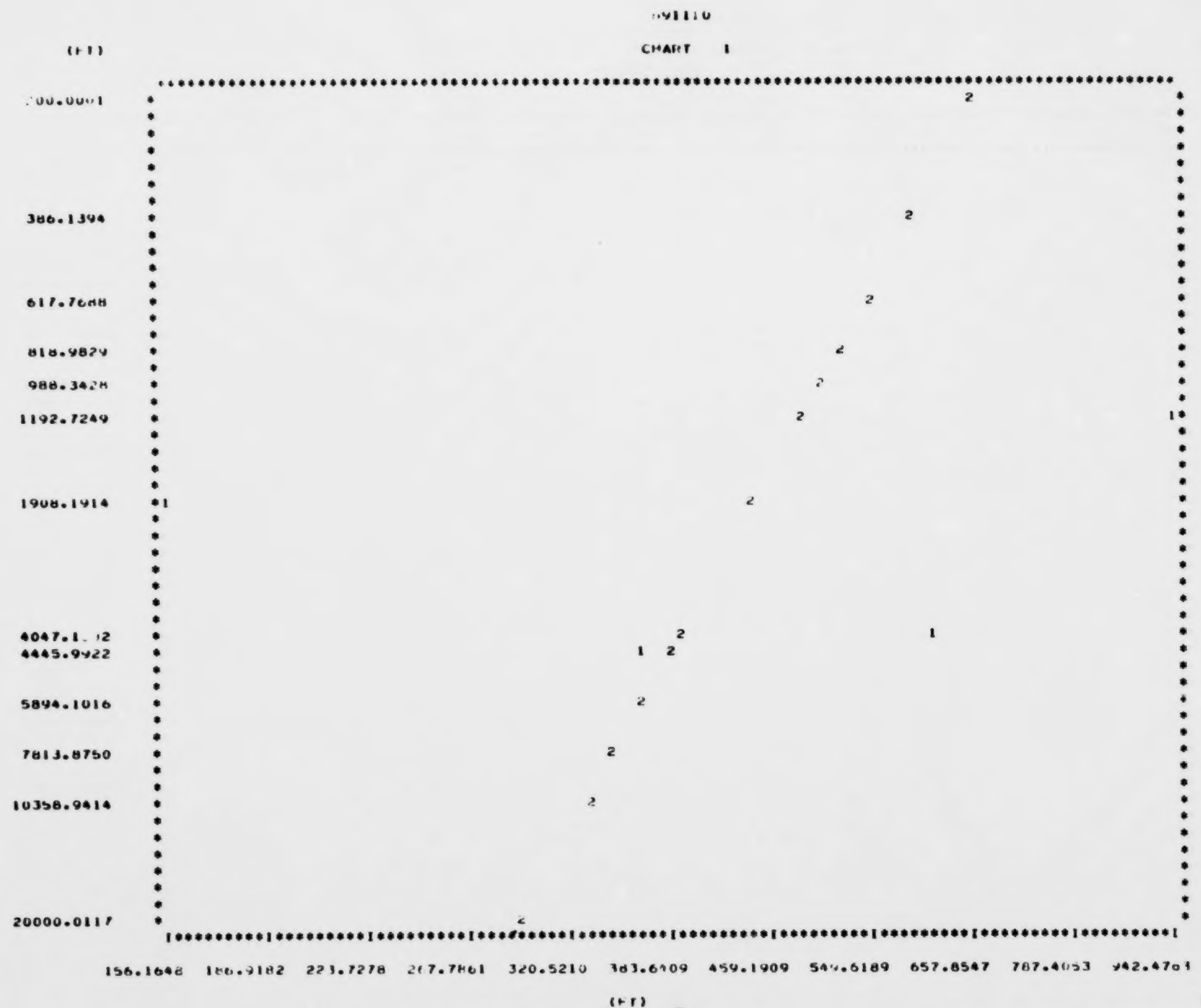


Fig. 74
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= -0.17696
B2= 7.44279

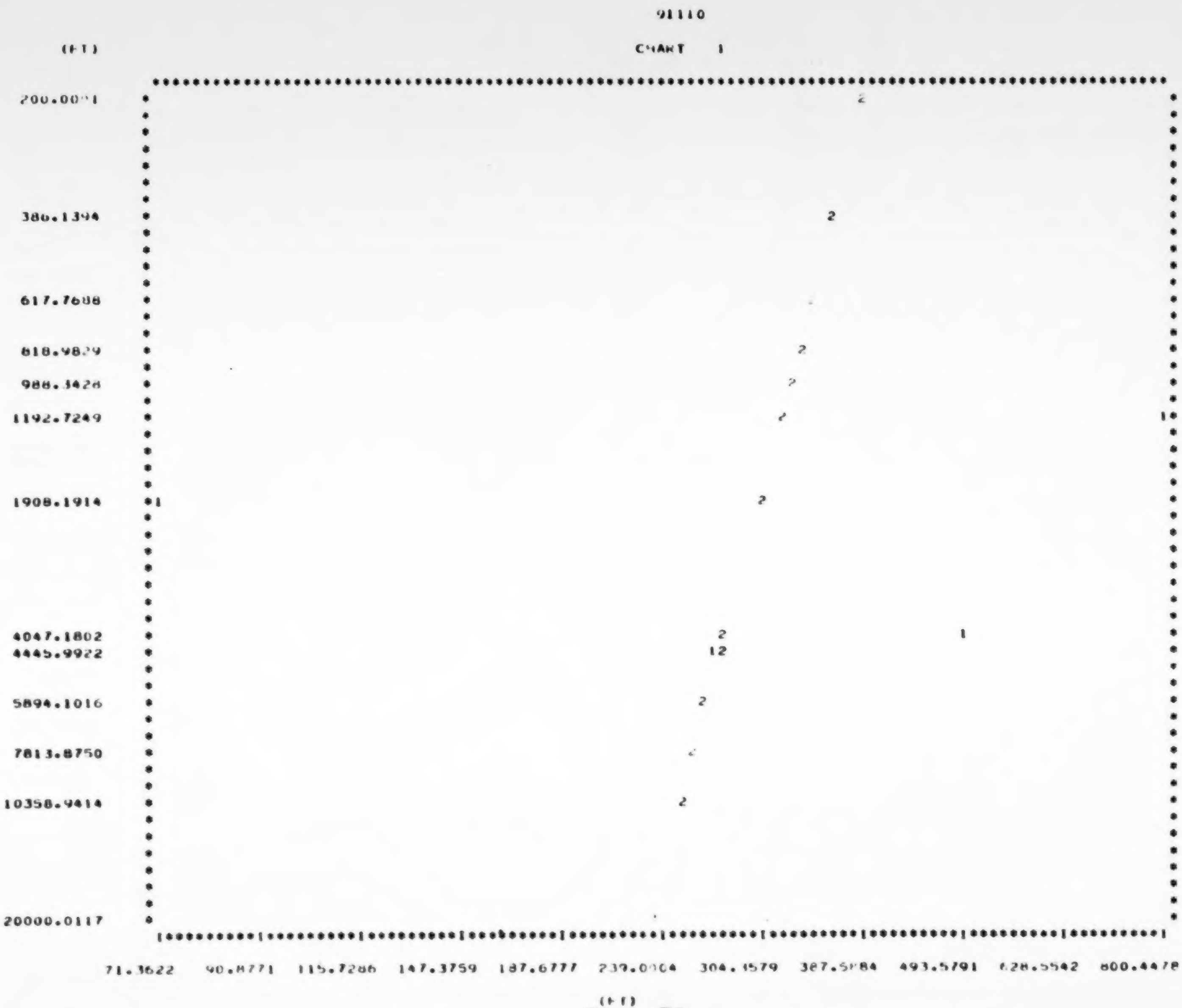


Fig. 75
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= -0.11280
B2= 6.57631

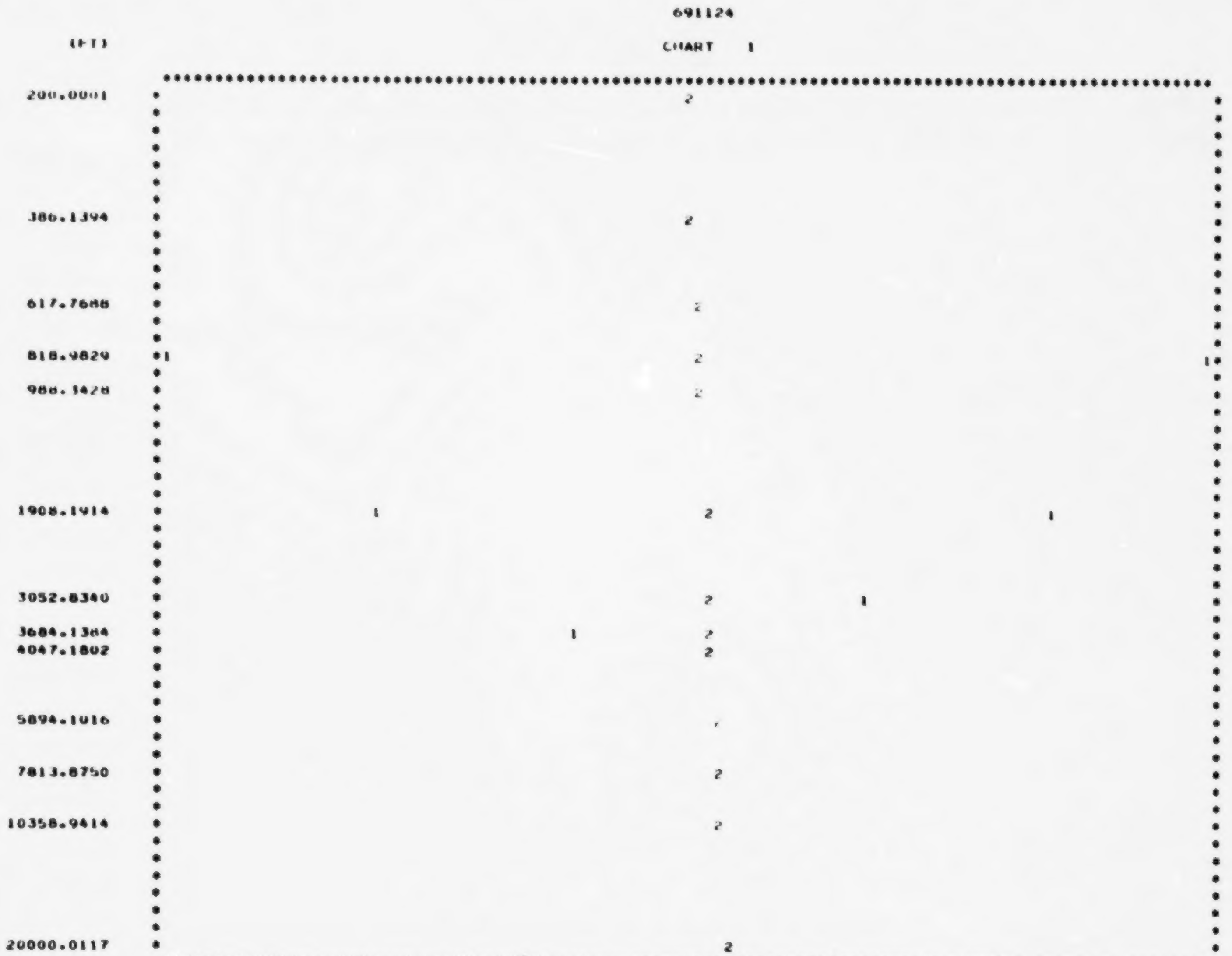


Fig. 76

DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.00756
B2= 6.17025

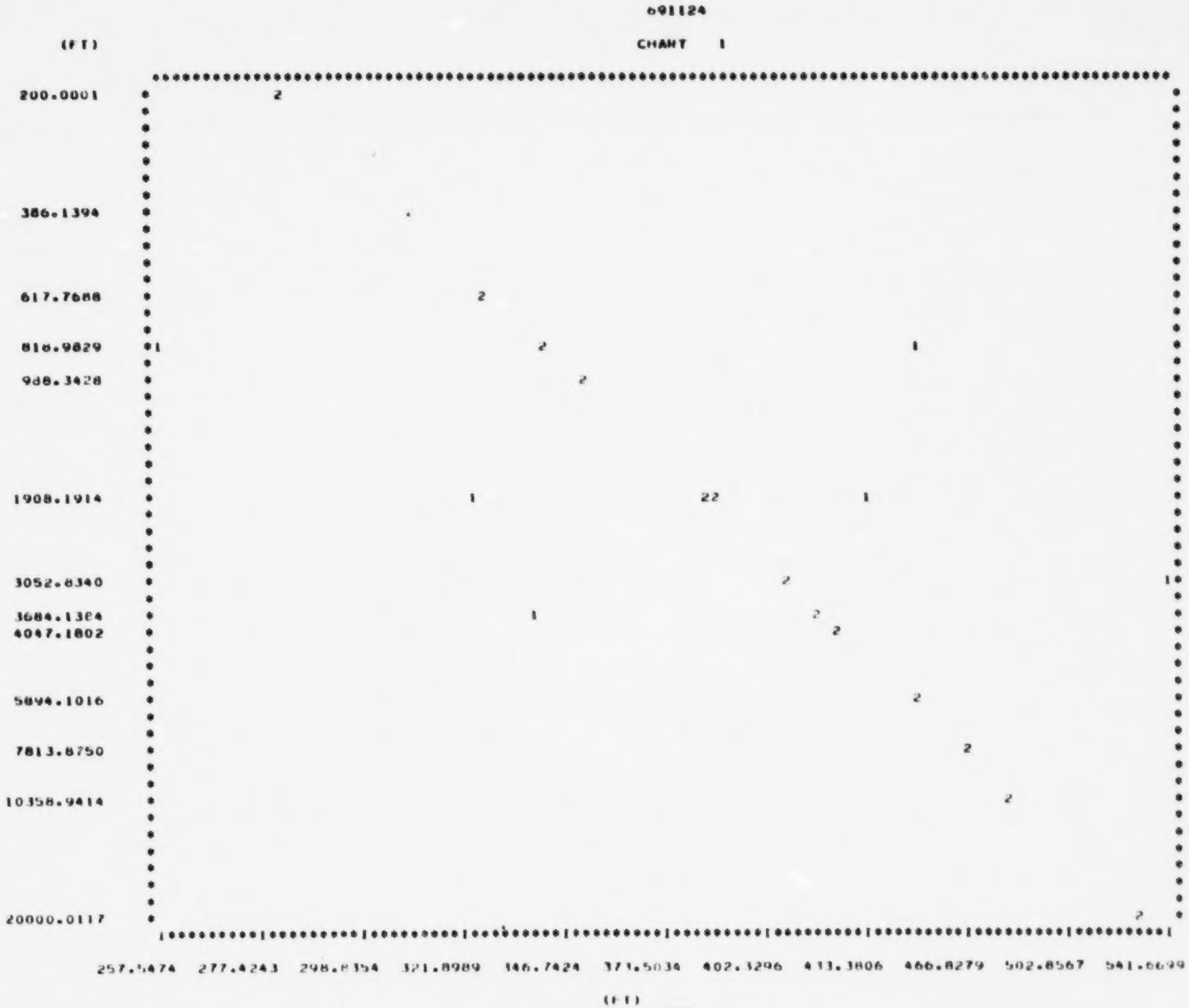


Fig. 77
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.13635
B2= 4.92377

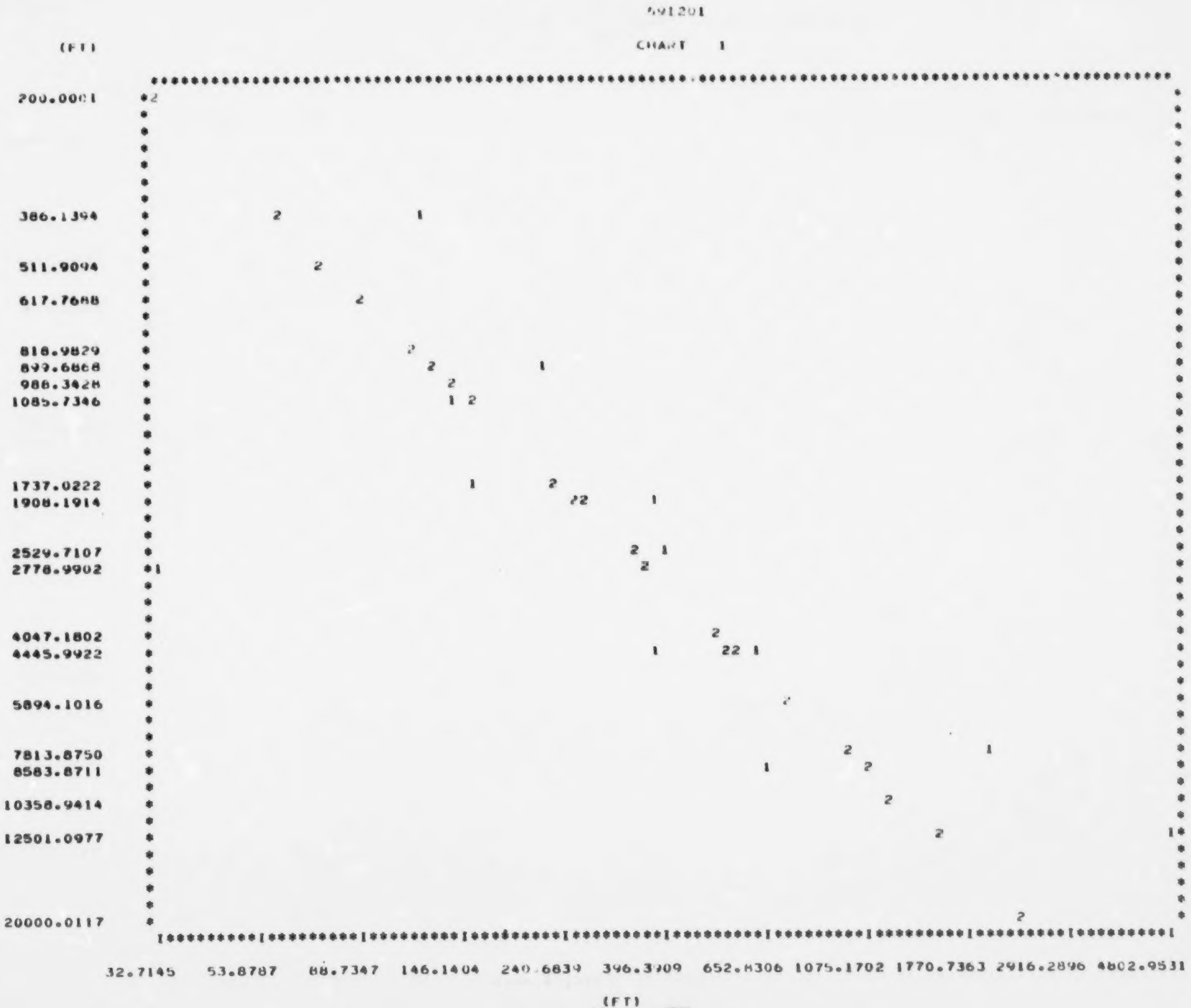


Fig. 78
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.02316
B2= -1.40340

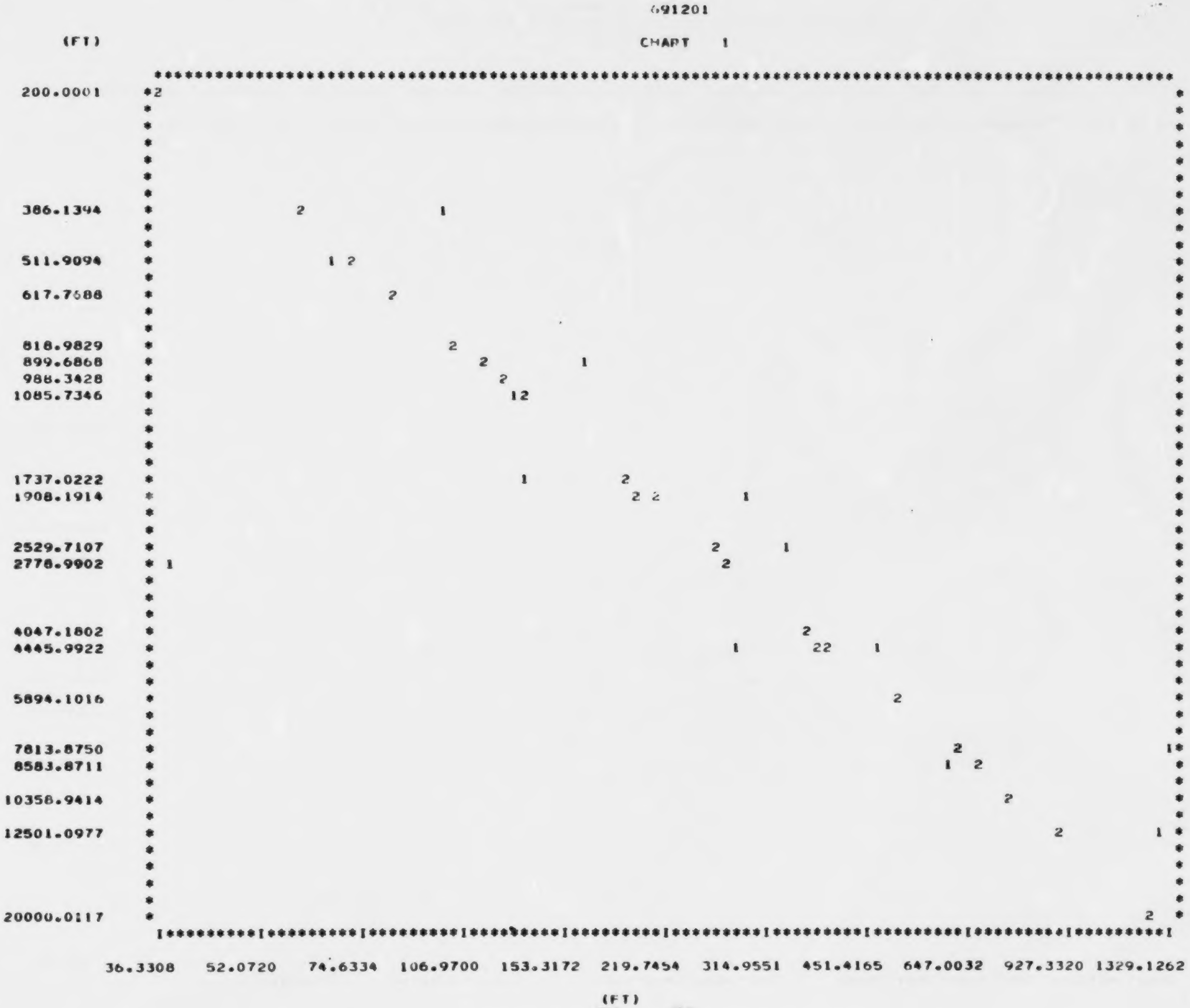


Fig. 79
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.77329
B2= -0.50449

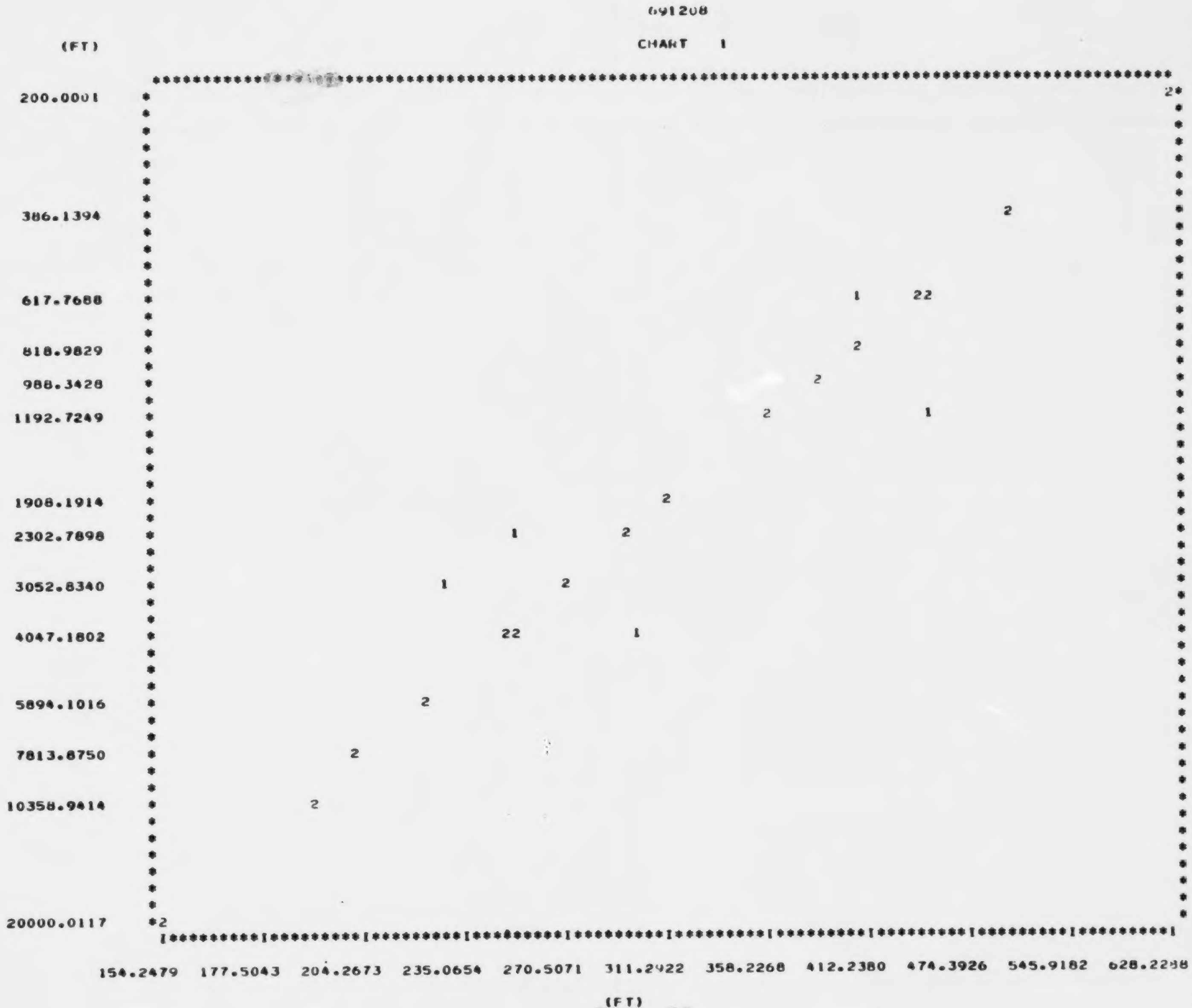


Fig. 80
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= -0.30495
B2= 8.05862

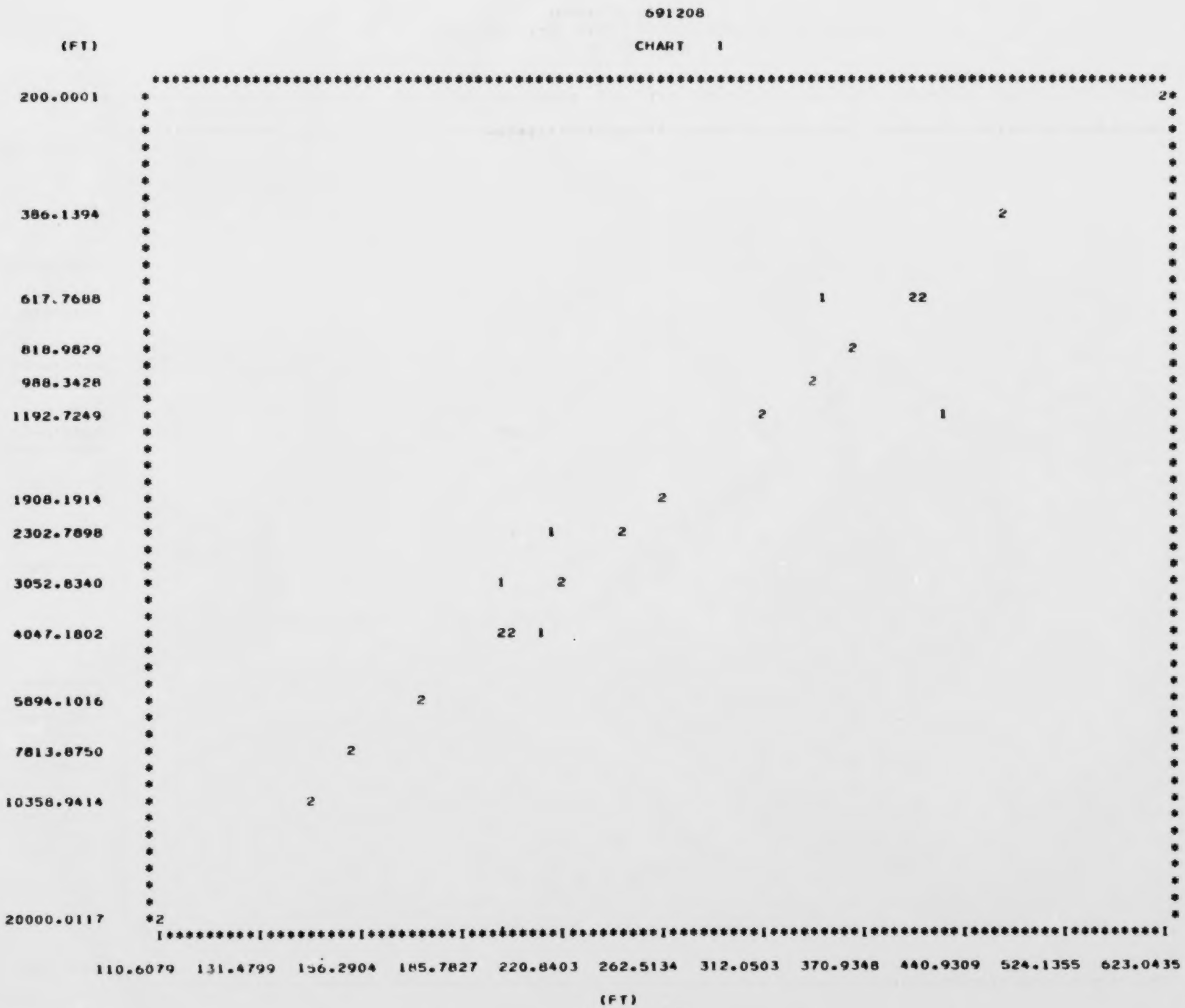


Fig. 81

DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= -0.37537
B2= 8.42342

691215

CHART 1

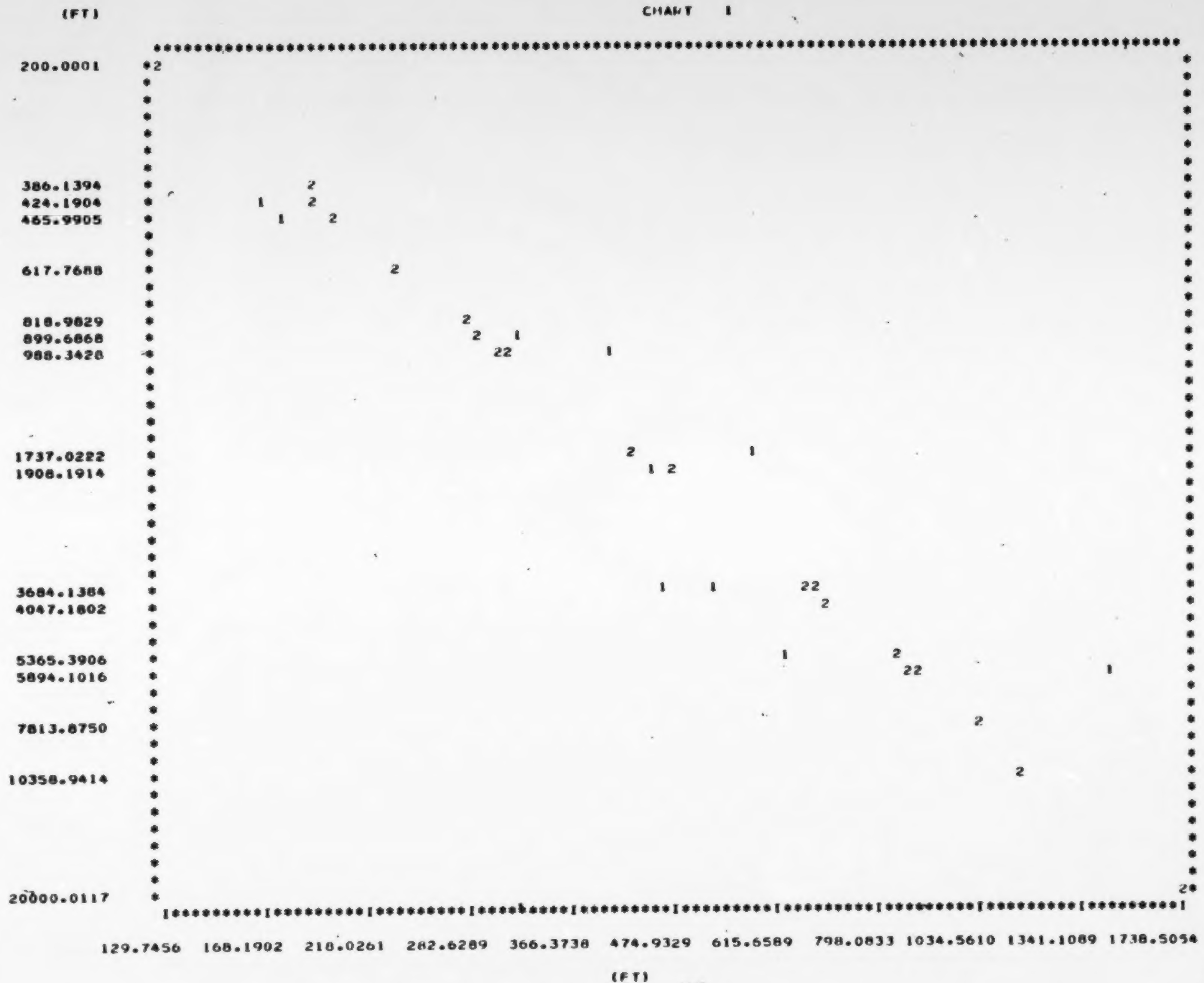


Fig. 82
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.56354
B2= 1.87975

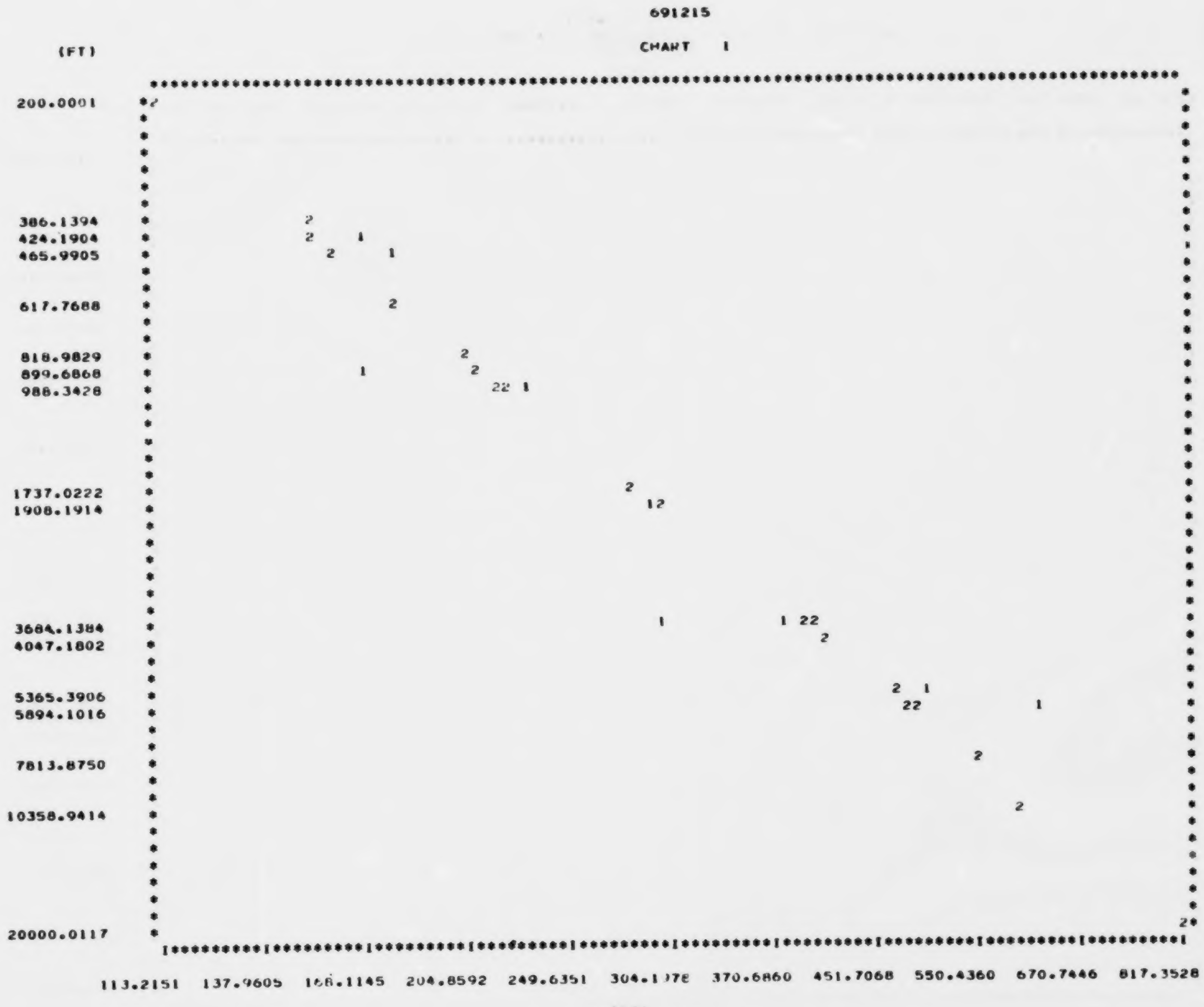


Fig. 83
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.42925
B2= 2.45497

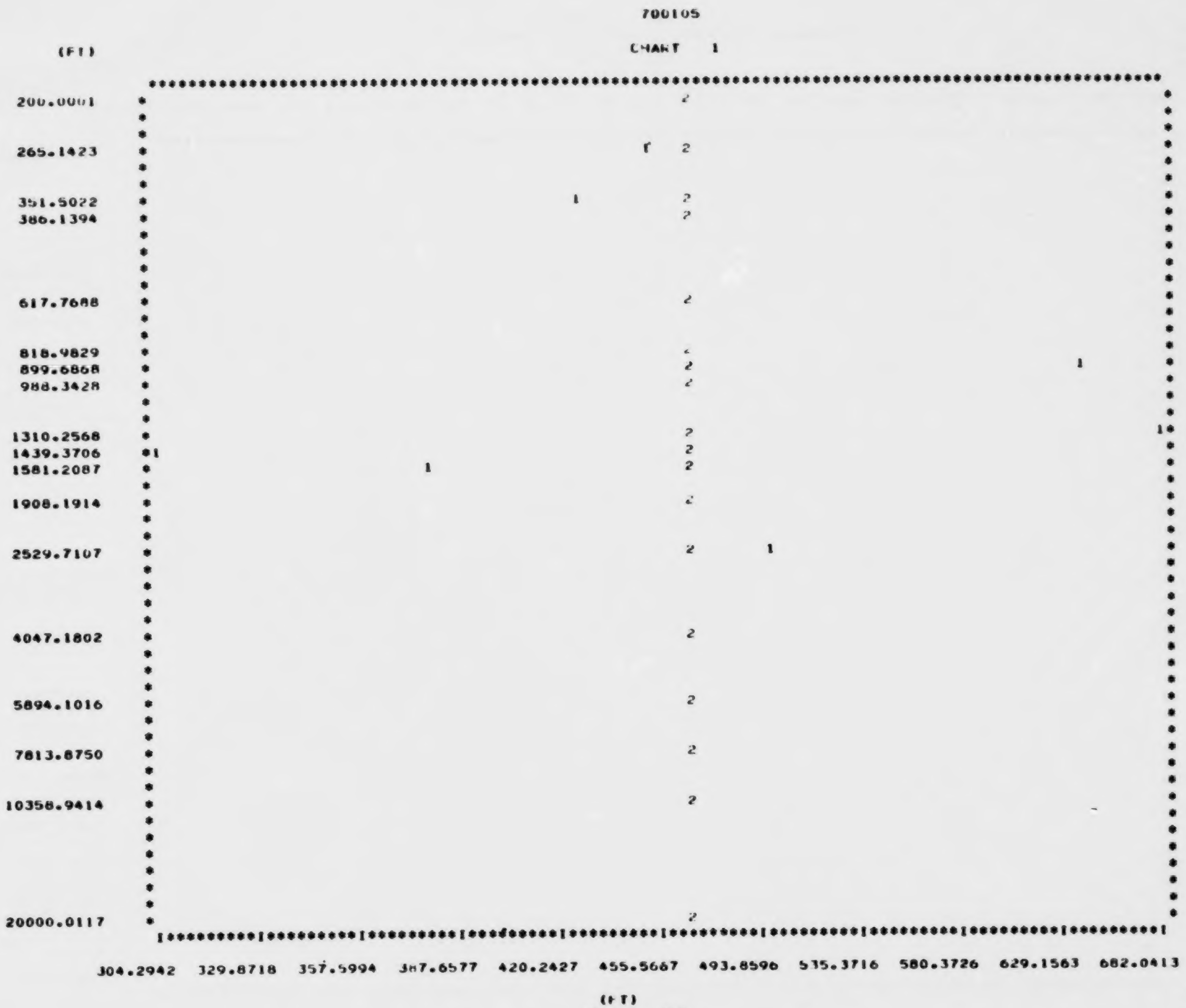


Fig. 84
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.00073
B2= 6.14327

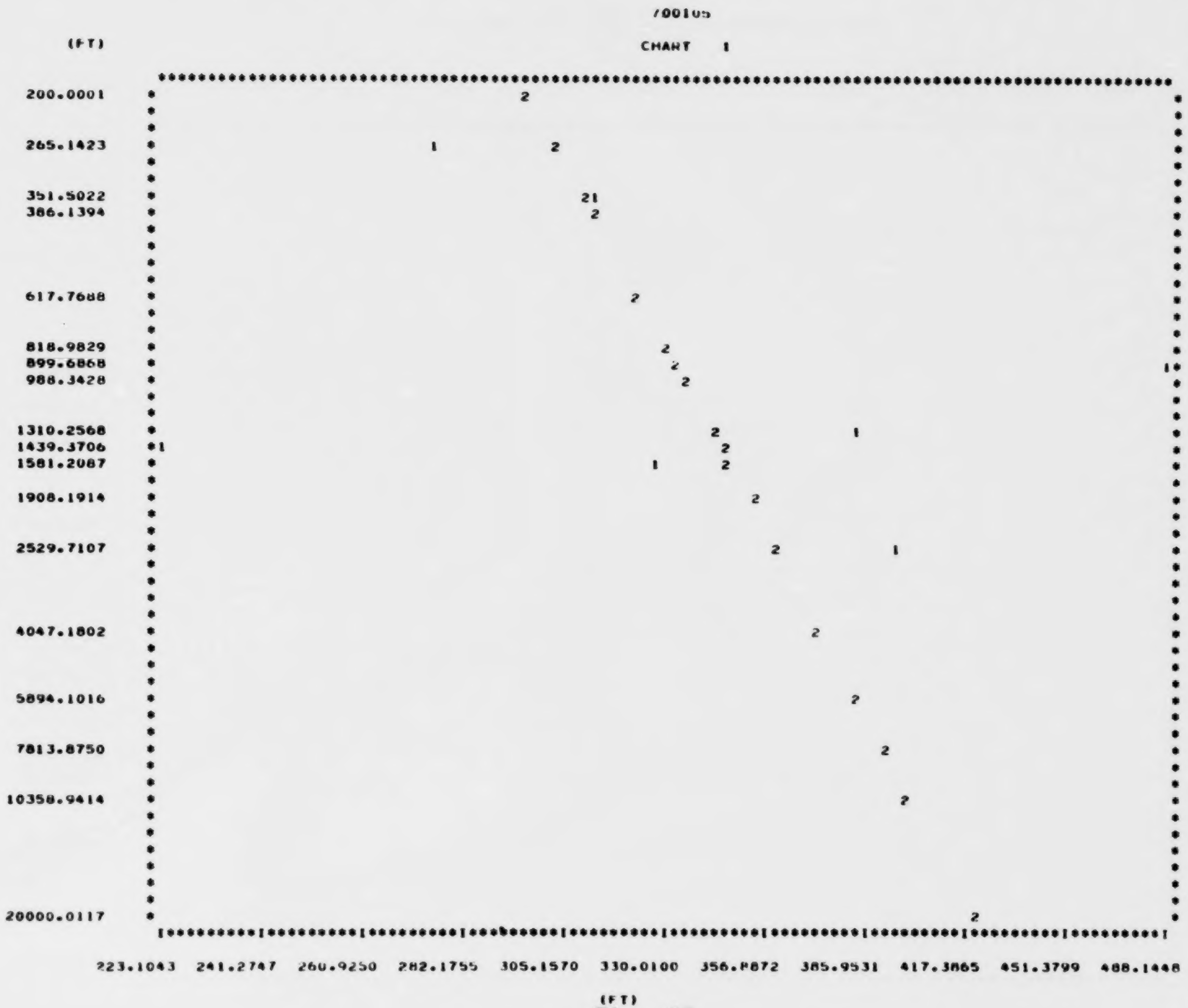


Fig. 85
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.07591
B2= 5.29350

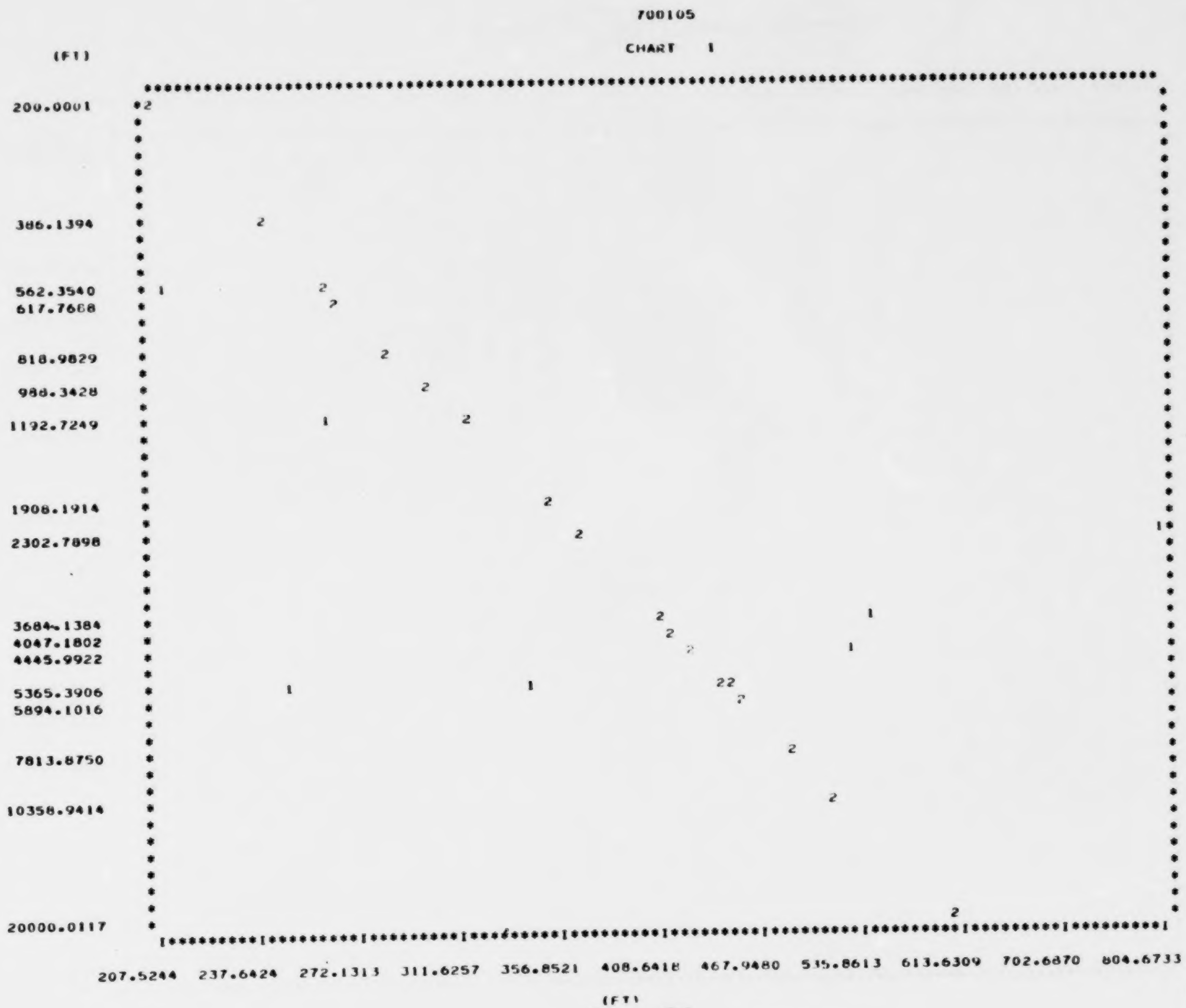


Fig. 86
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.23373
B2= 4.09690

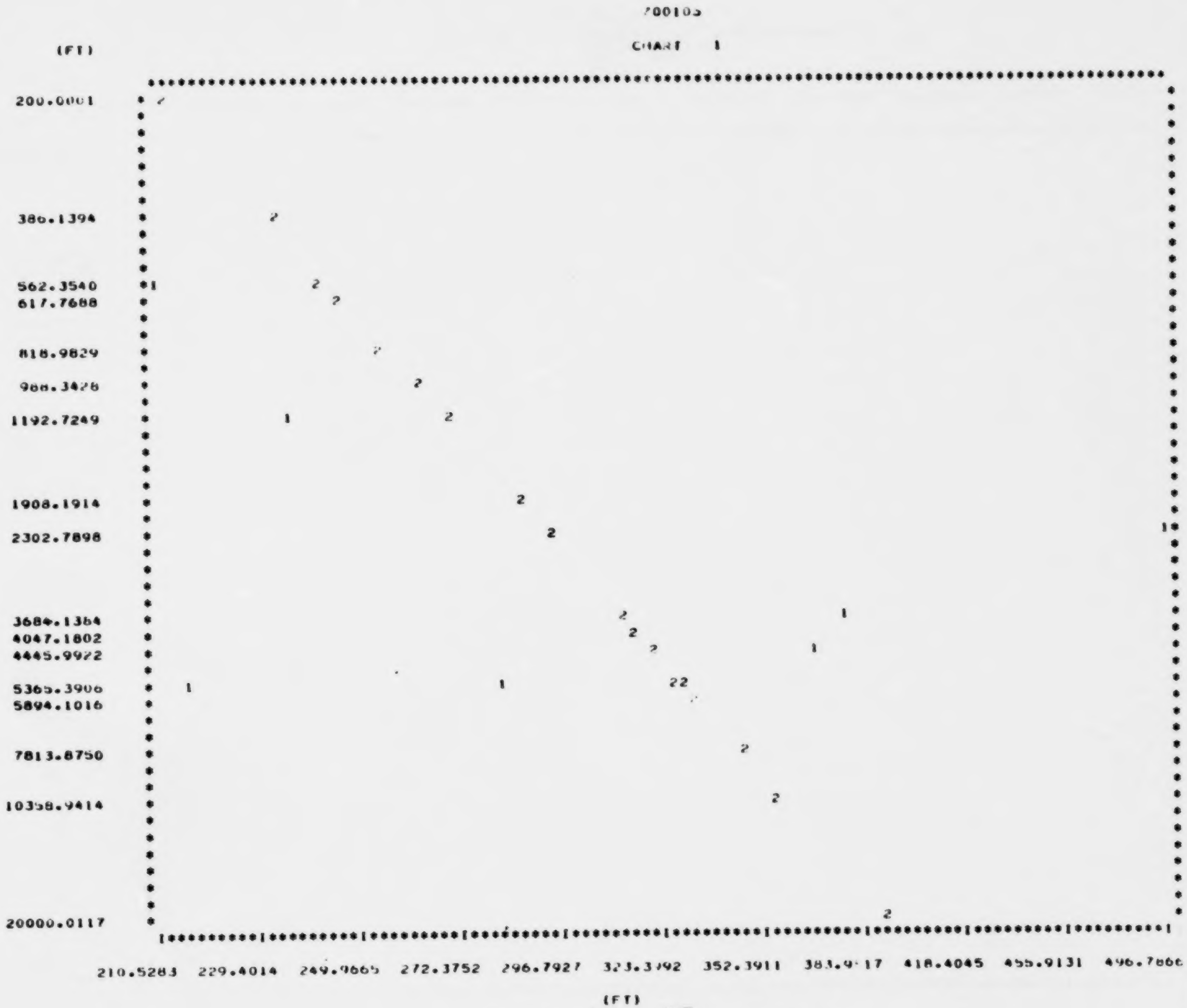


Fig. 87
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.13199
B2= 4.66232

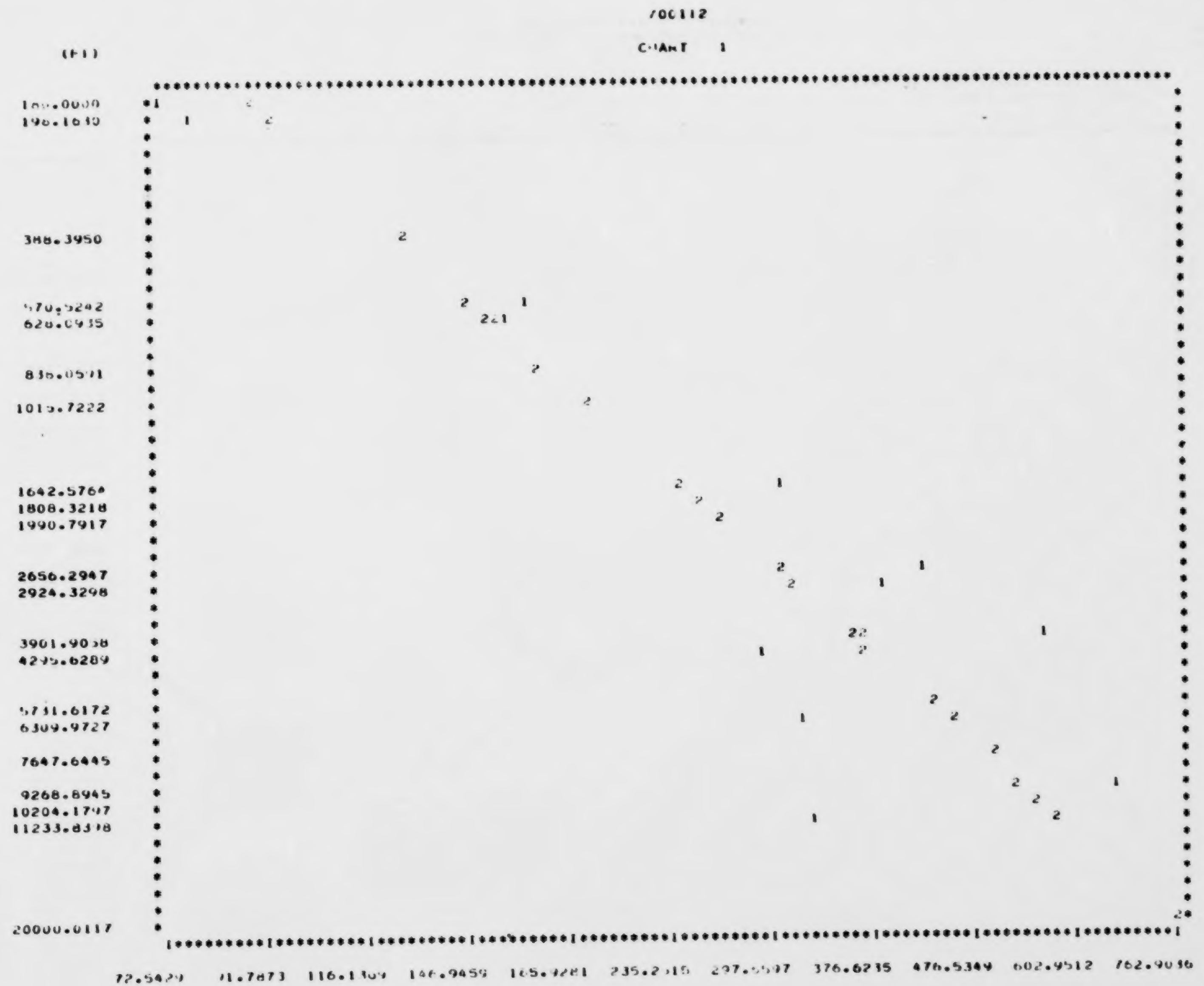


Fig. 88

DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1- 0.45174
B2- 2.14356

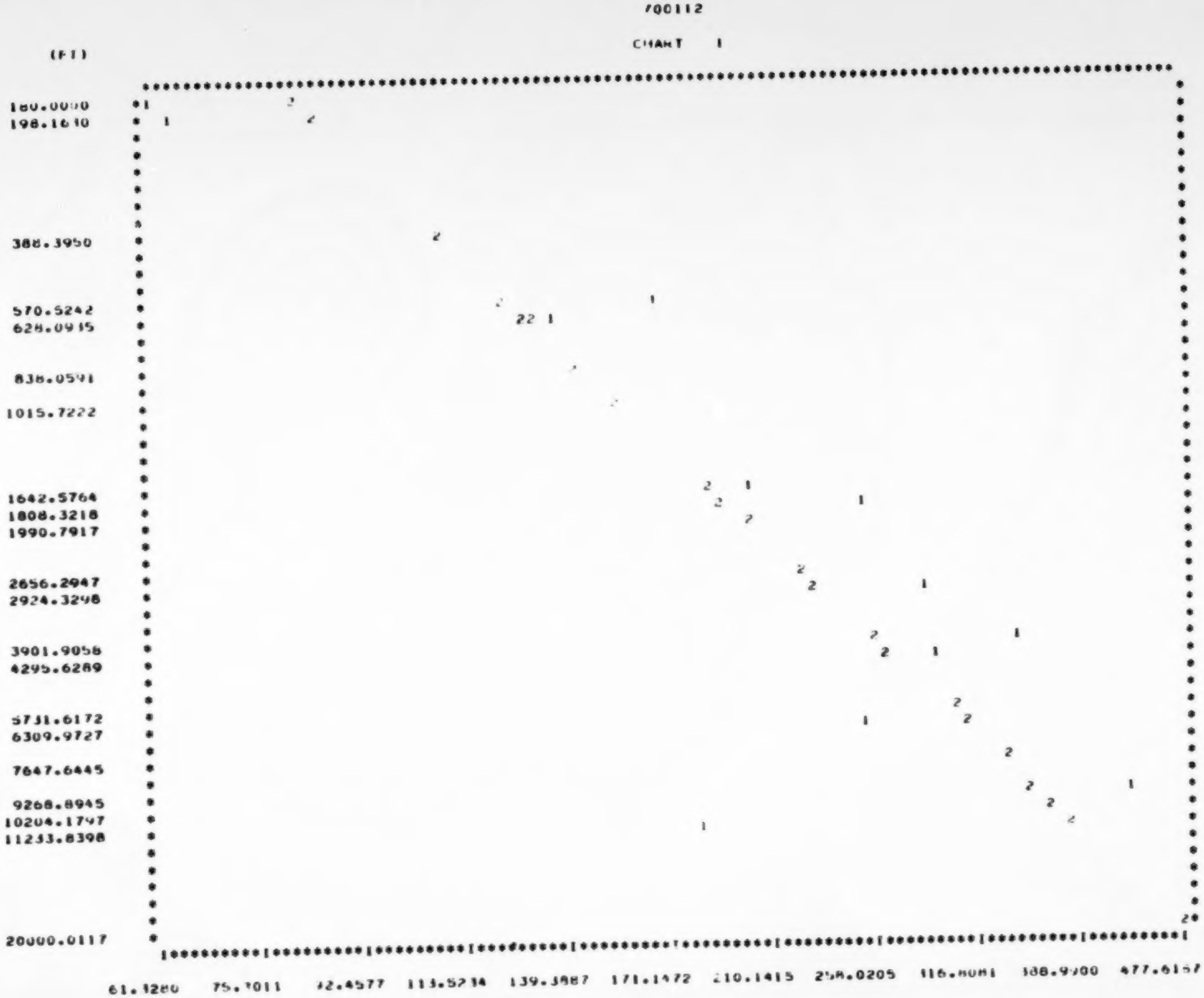


Fig. 89
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.37393
B2= 2.46561

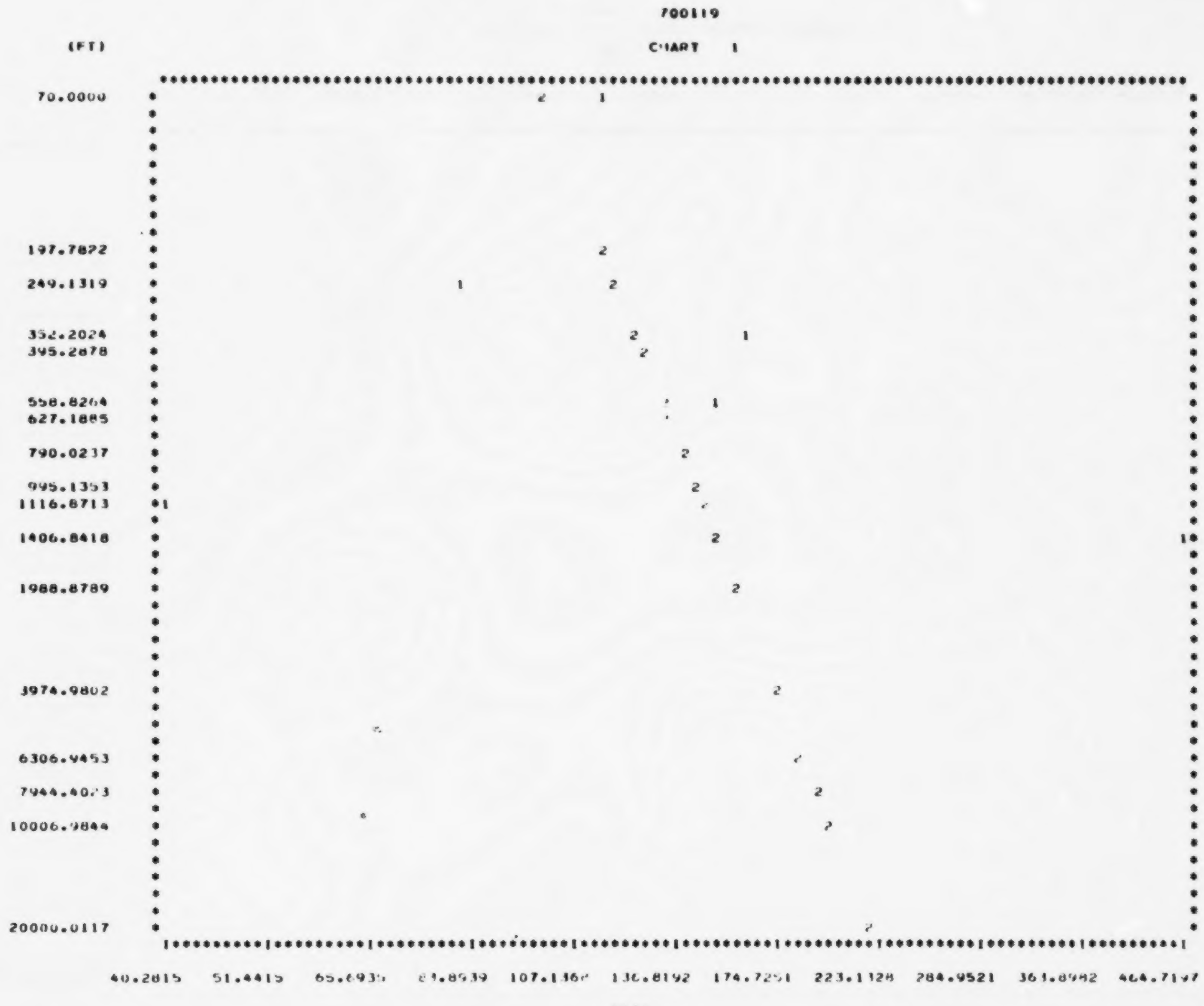


Fig. 90
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.13949
B2= 4.02014

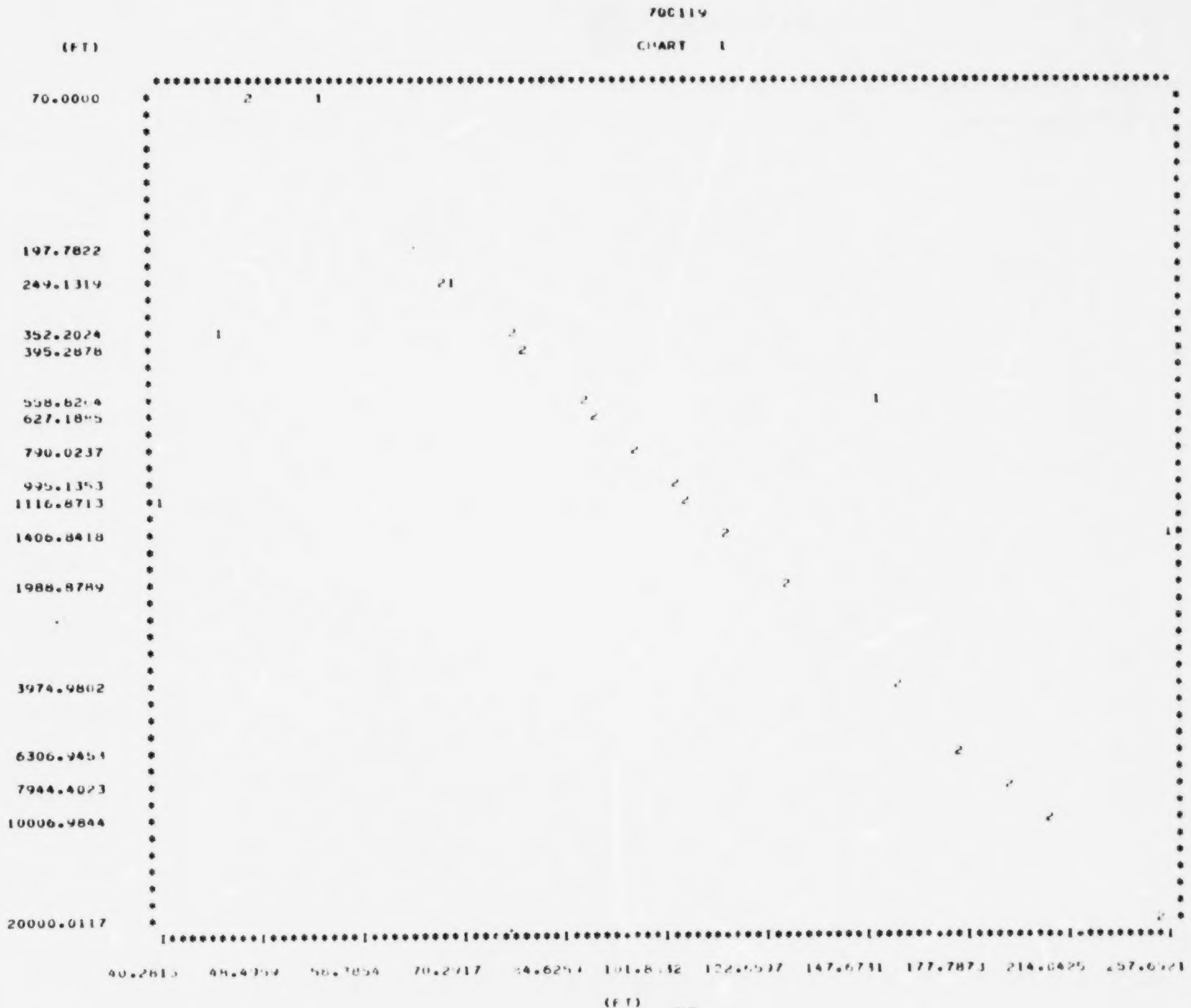


Fig. 91
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.27546
B2= 2.60828

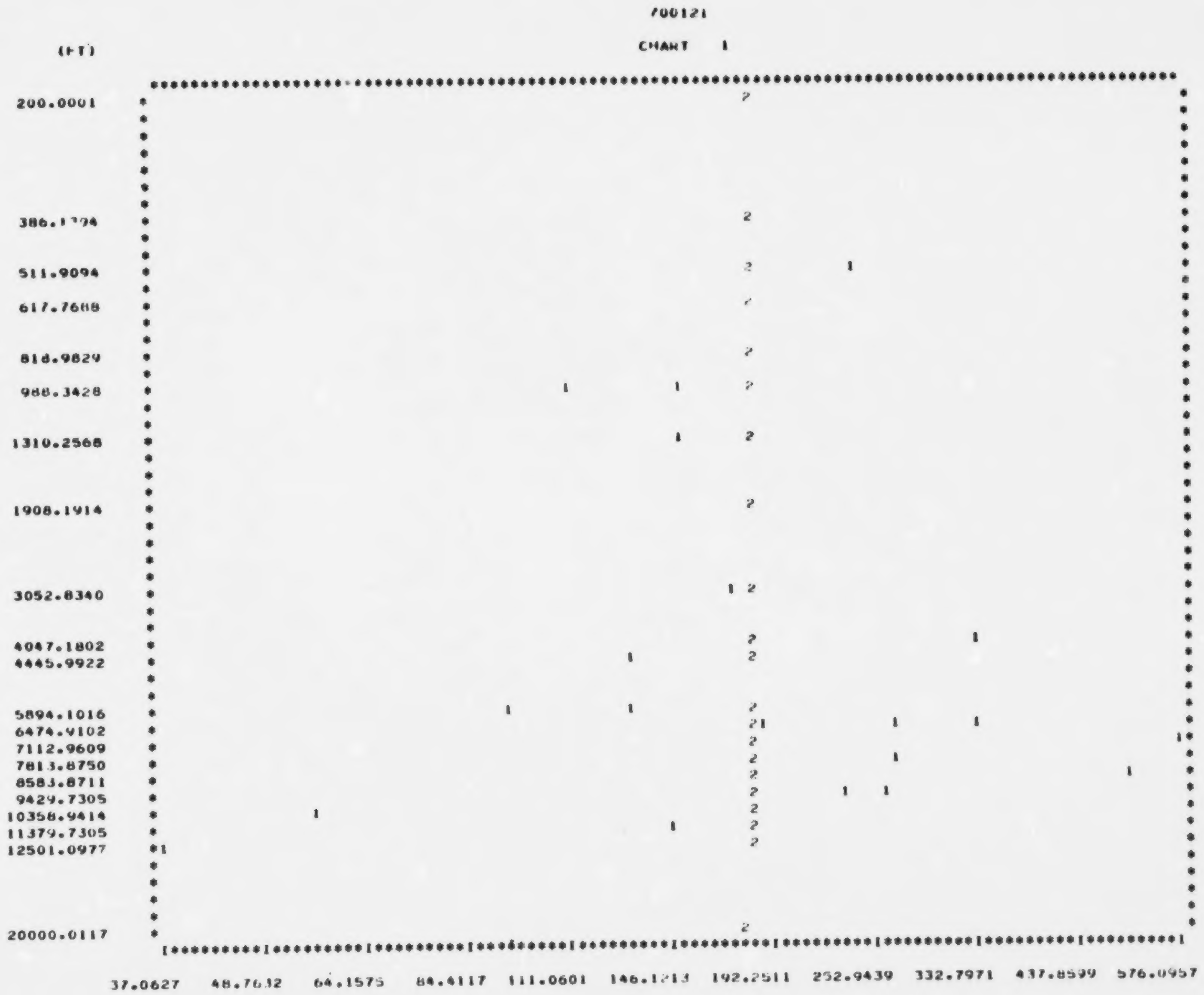


Fig. 92
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= -0.00207
B2= 5.22439

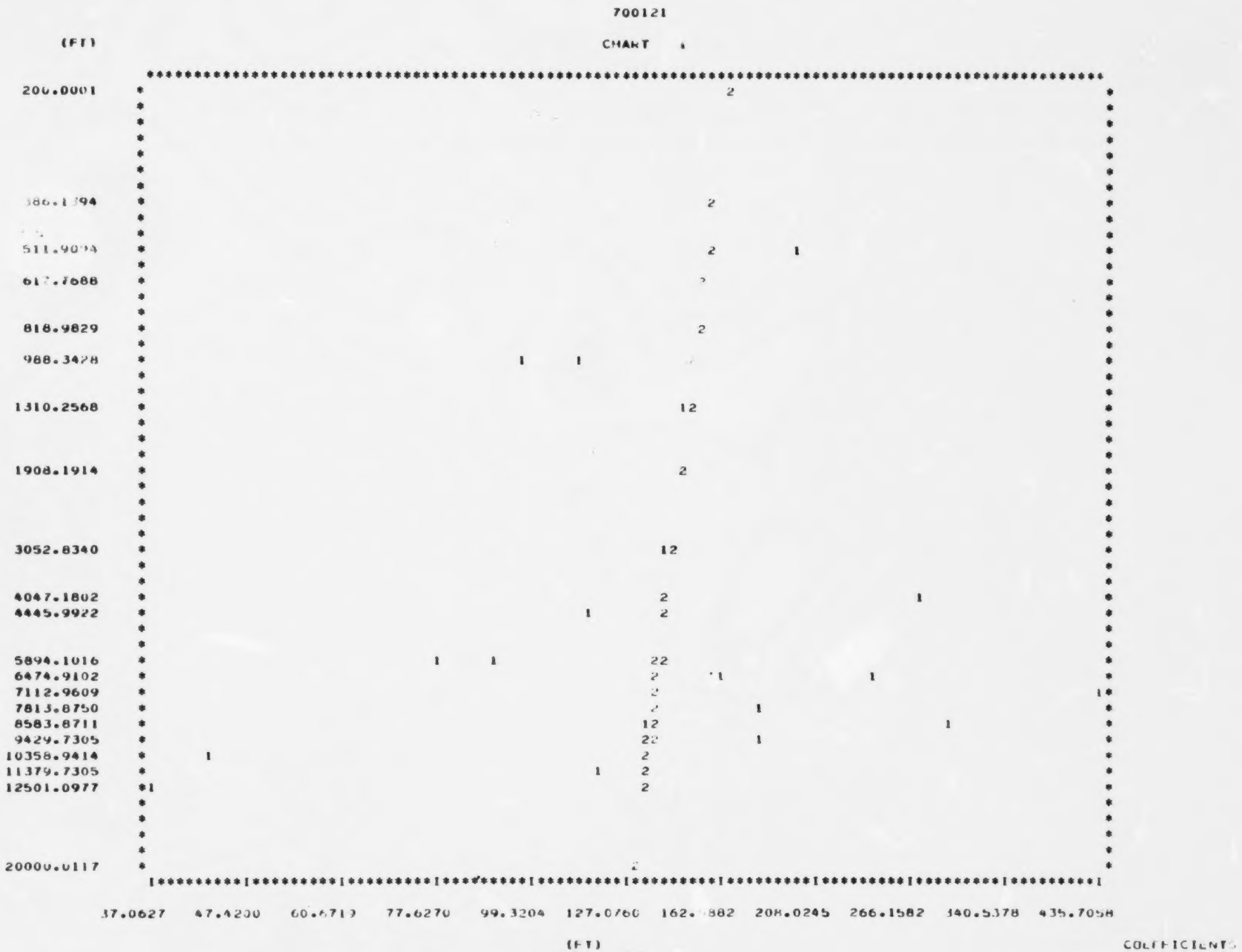


Fig. 93
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= -0.05170
B2= 5.39189

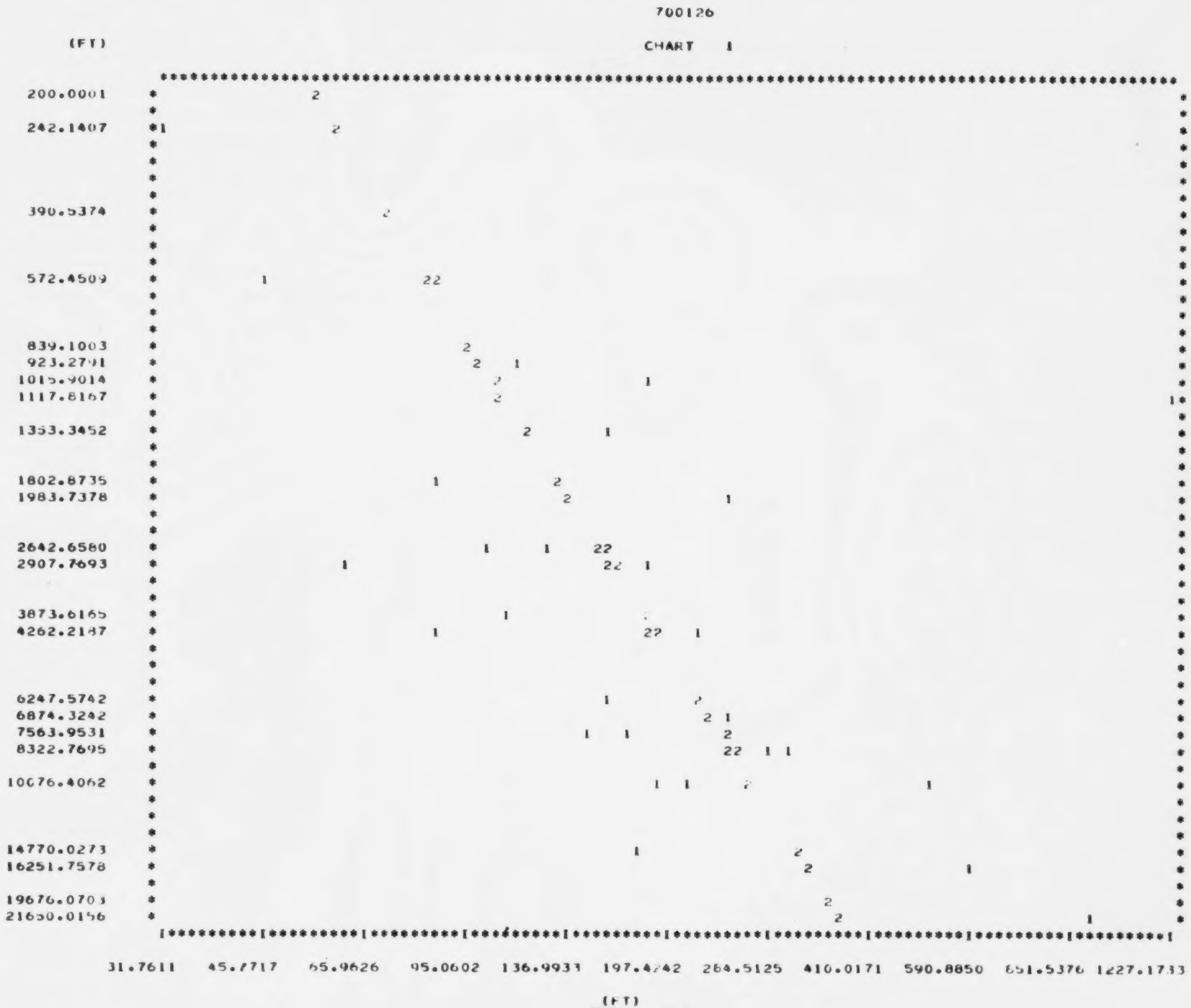


Fig. 94
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.40952
B2= 1.03674

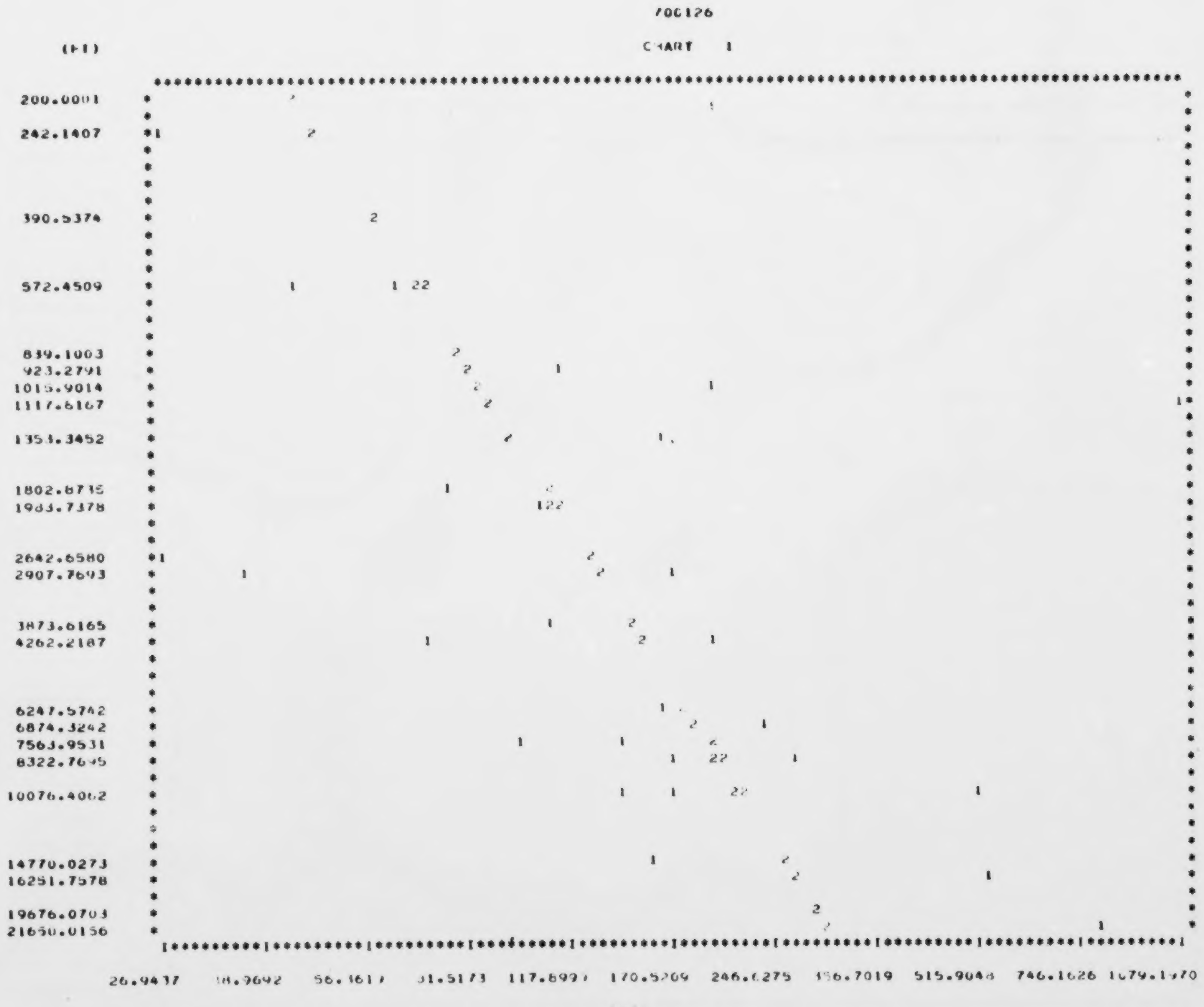


Fig. 95
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
Q1= 0.4079
Q2= 1.04663

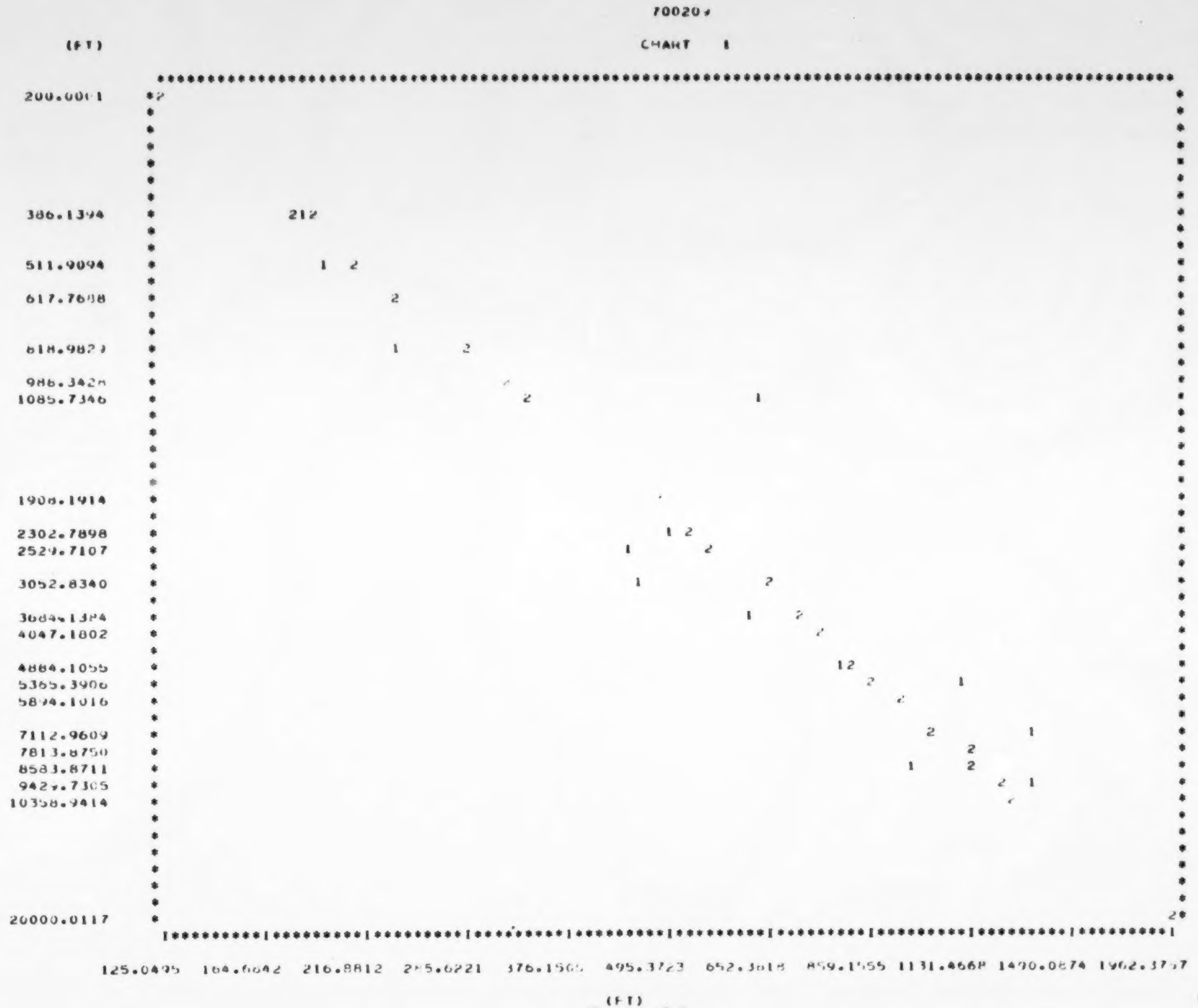


Fig. 96
DISTANCE V.S. GAUSSIAN FIT STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.37785
B2= 1.66111

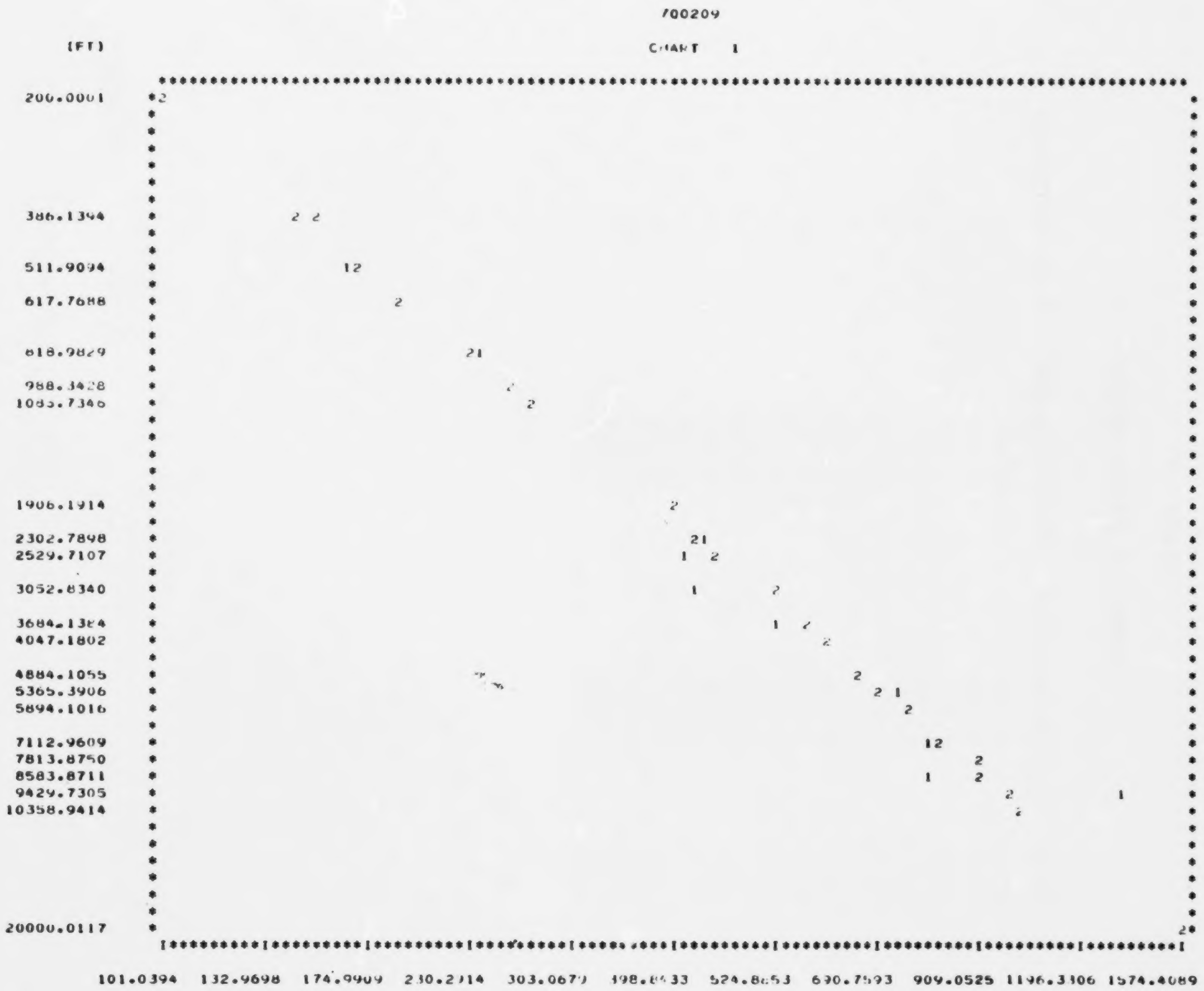


Fig. 97
DISTANCE V.S. SAMPLE STANDARD DEVIATION
(LOG-LOG PLOT)

COEFFICIENTS
B1= 0.59631
B2= 1.45605

TABLE 23

Power of Plume Spread

Date	Bl Guassian Fit	Bl Sample Fit	# of Transects
8/26	0.577	0.543	28
8/27	0.447	0.248	5
9/16	0.178	0.190	5
9/29	0.595	0.567	15
10/15	0.629	0.572	9
11/3	0.411	0.671	5
11/10	-0.177	-0.113	4
11/24	0.008	0.136	6
12/1	0.923	0.773	13
12/8	-0.305	-0.375	5
12/15	0.563	0.429	10
1/5	0.007	0.076	7
1/5	0.234	0.132	7
1/12	0.454	0.374	13
1/19	0.139	0.295	6
1/21	-0.002	-0.052	21
1/26	0.409	0.408	28
2/9	0.598	0.596	13

of too little data and are erroneous. The 1/21 experiment was a one gallon dye slug. This amount of dye was insufficient to be detected far from the outfall, resulting in an erroneous negative value. If one considers only the experiments with more than 7 transects (not including 1/21) the spread of the plume is seen to vary from $x^{.409}$ to $x^{.923}$ power.

In general the Gaussian fit numbers correspond quite well to the numbers given by the sample fit. The differences arise mainly when the concentration is spread out in the cross-stream direction where the Gaussian fit standard deviation is larger than the sample fit standard deviation. We feel that the Gaussian fit method is generally a more reliable method for estimating the width of the plume.

The total dilution that the effluent undergoes after leaving the outfall pipe by mixing and dispersion with the shelf is calculated for every transect. Total dilution is the peak dye concentration of a transect divided by the initial concentration in the sewage lift station. Since the peak concentration is calculated by both the Gaussian fit analysis and the sample fit analysis then total dilution will also be calculated by these two approaches. Figures 98-133 are log-log plots of the downstream distance against total dilution calculated by the two methods. The "ones" are the actual data and the "twos" represent a least square fit using a second degree polynomial regression function of the form:

$$Y = c1X^2 + c2X + c3 \qquad (20)$$

where $Y = \ln$ (total dilution)

$X = \ln(x)$

The coefficients c1, c2, and c3 were computed and plotted in the lower right hand corner of Figures 98-133.

These plots show good agreement between the two techniques for computing the peak concentration of each transect. The Gaussian peak concentration will normally underestimate the peak slightly, making the Gaussian total dilution slightly less than would be expected and therefore, a more conservative number from a pollution standpoint.

If one assumed a value of 30×10^6 Total Coliforms (T.C.)/100 ml for the number of bacteria in the raw sewage of the Pompano Lift Station, then this initial concentration would have to undergo a dilution of 3.33×10^{-5} or less in order to be reduced down to the state standard of 1000 (T.C.)/100 ml for bathing water. It is evident from Figures 98-133 that dilution due to mixing and dispersion will not be sufficient to reduce the initial concentration of bacteria down to the standard in the 7400 feet distance from the outfall to shore. Only

690826

CHART 2

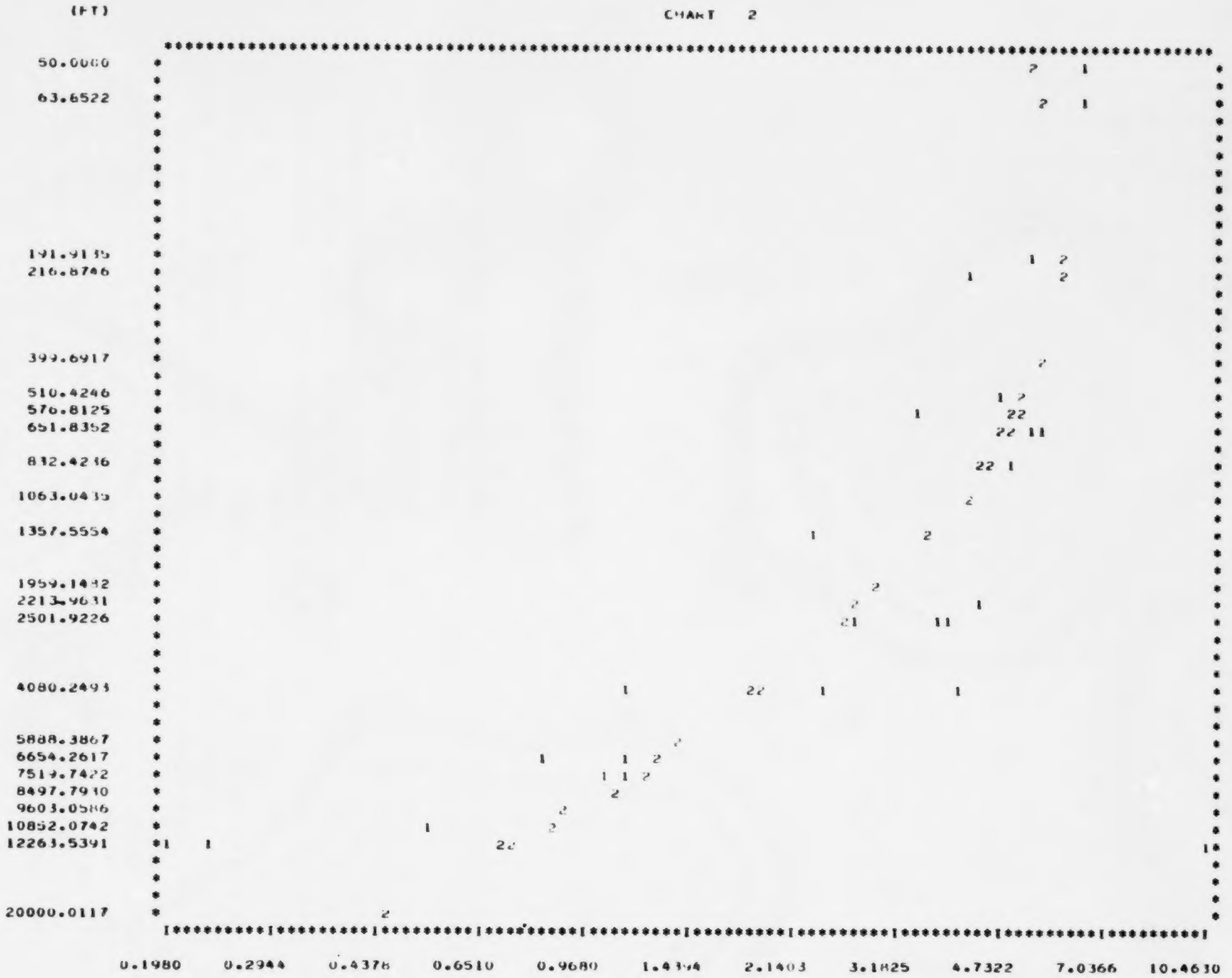


Fig. 98

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -9.10971
C2= 1.10792
C3= -0.73380

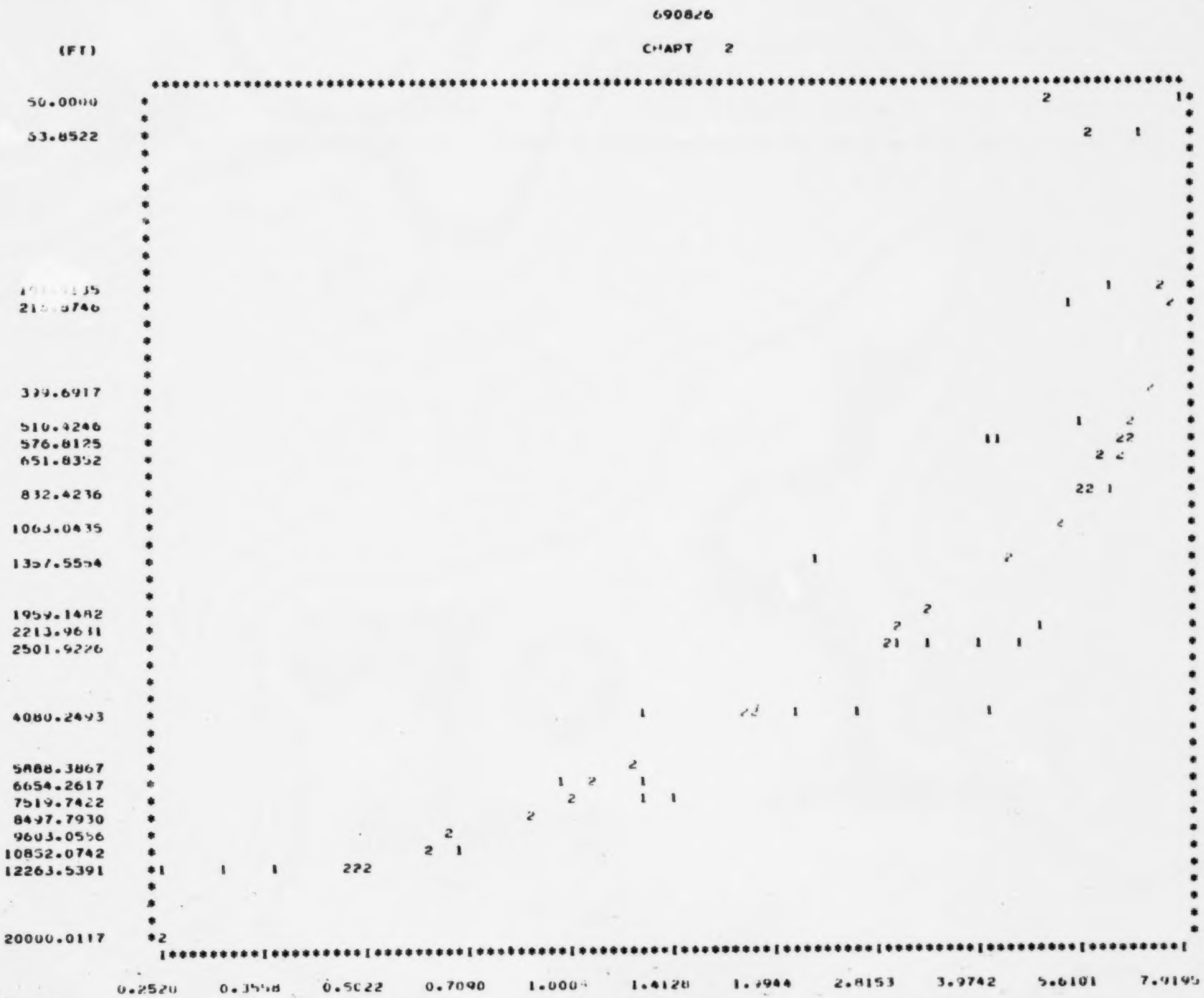


Fig. 99

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -[illegible].15903
C2= 1.03290
C3= -2.68822

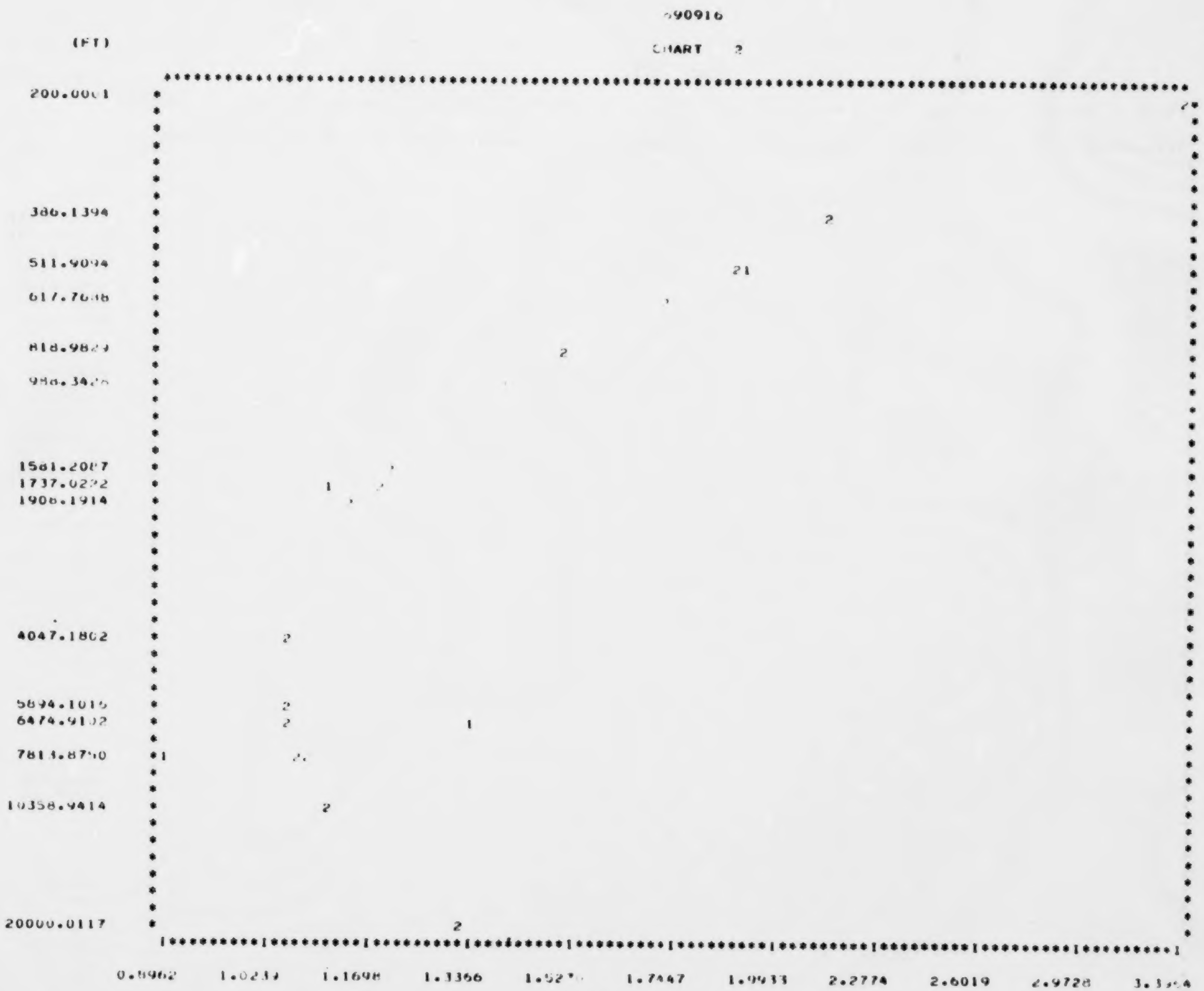


Fig. 100

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.11600
C2= -1.46708
C3= 0.57160

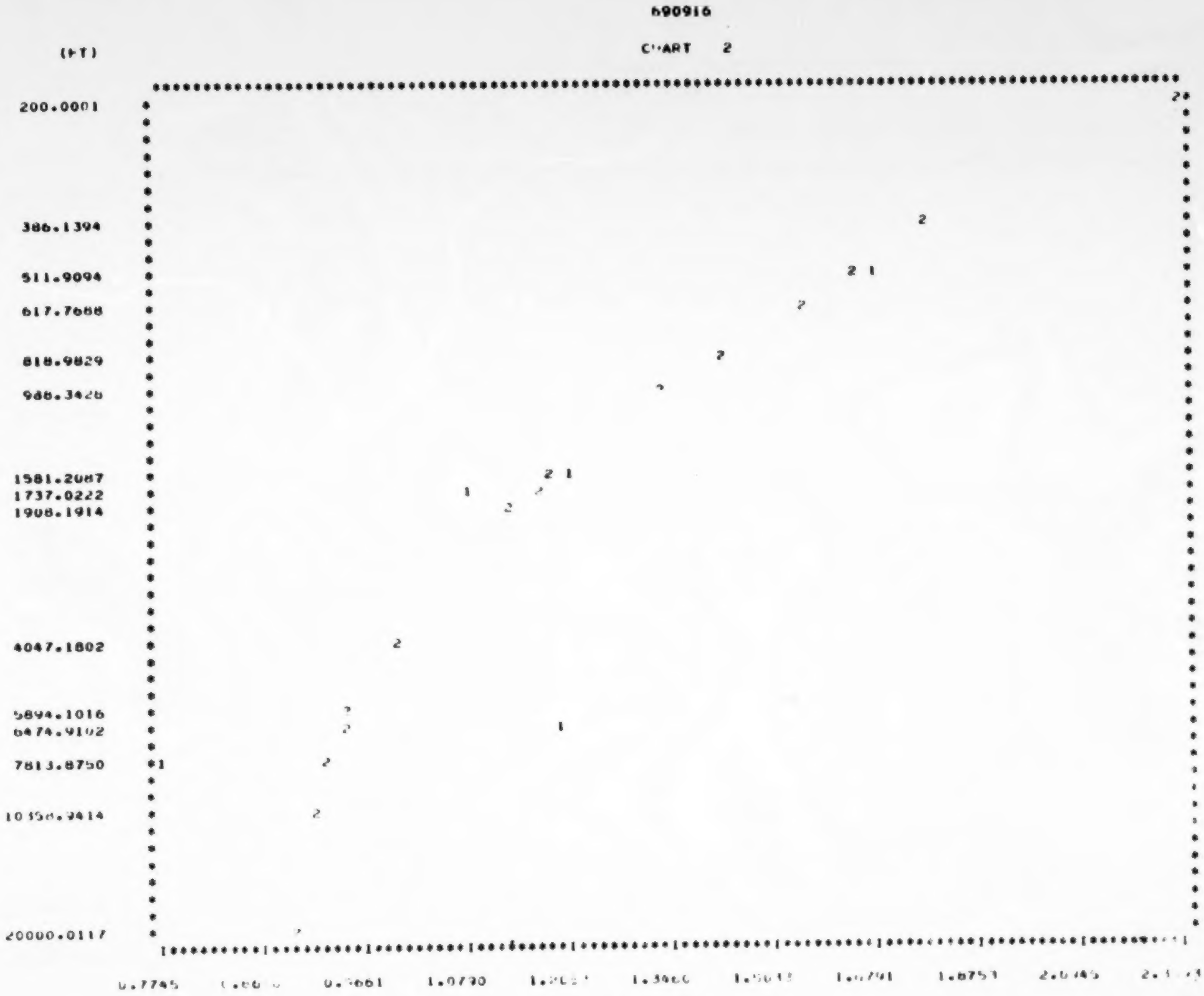


Fig. 101

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

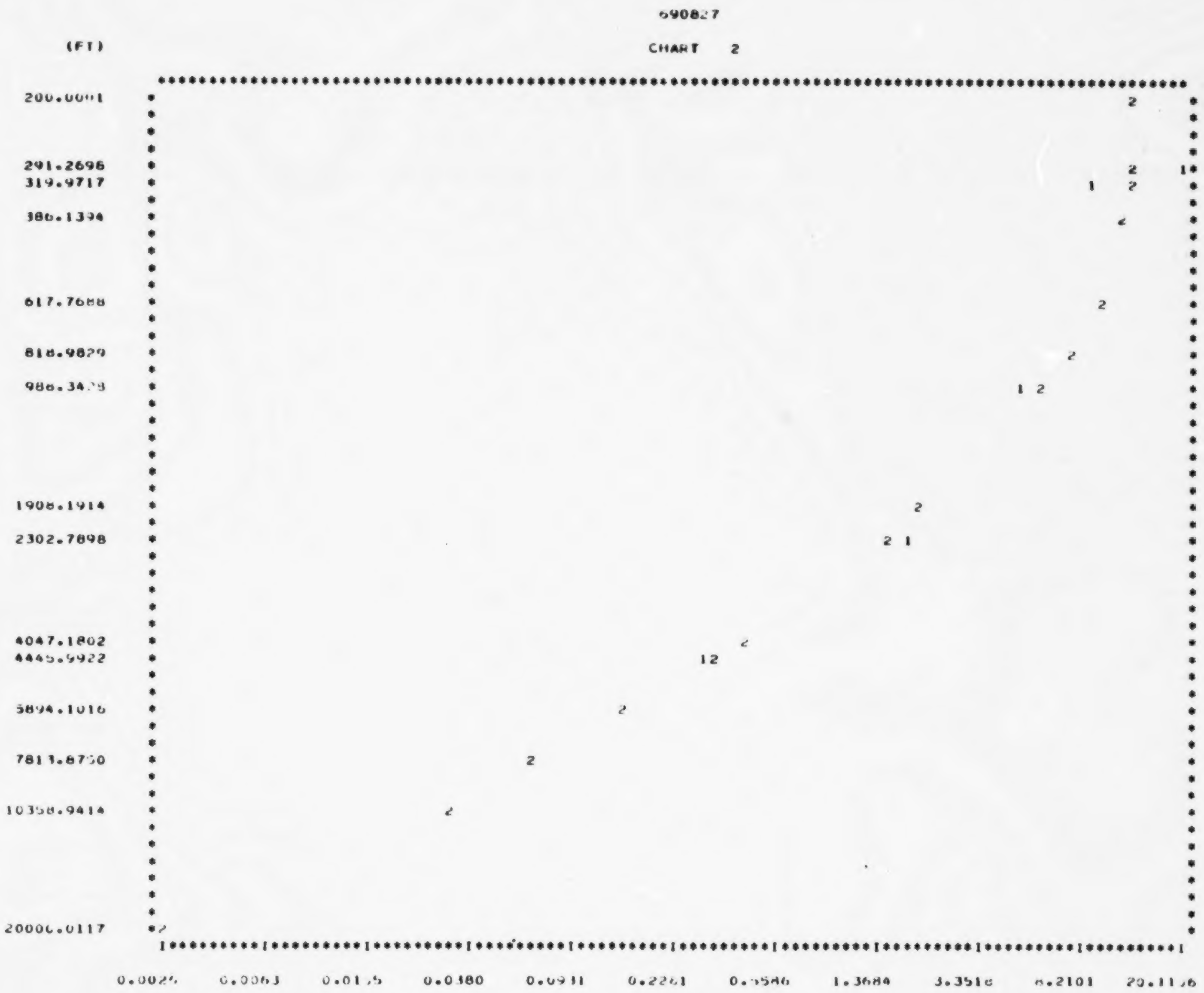


Fig. 102

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.45283
C2= 5.02457
C3=-10.89355

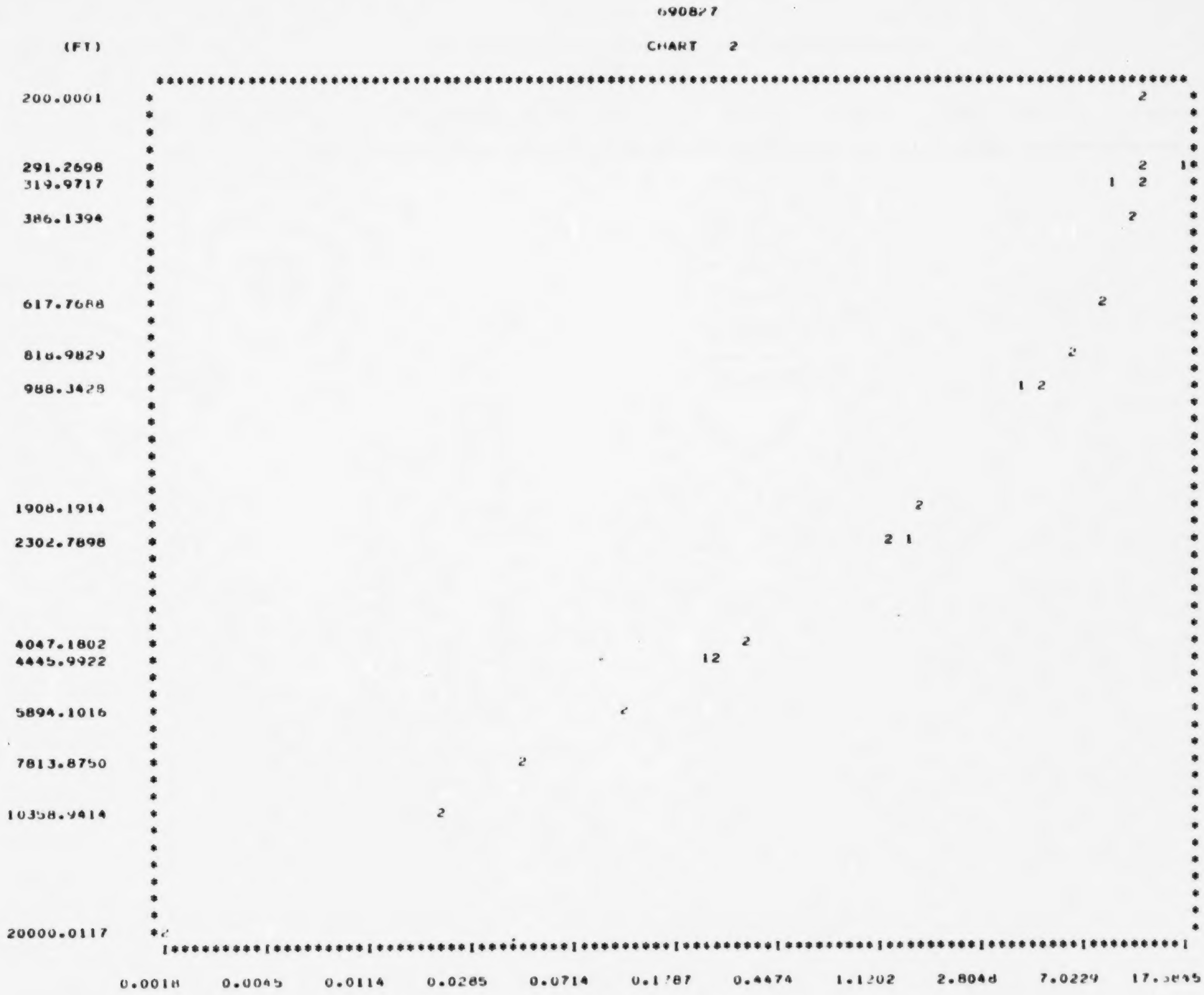


Fig. 103

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.45186
C2= 4.47512
C3=-10.65620

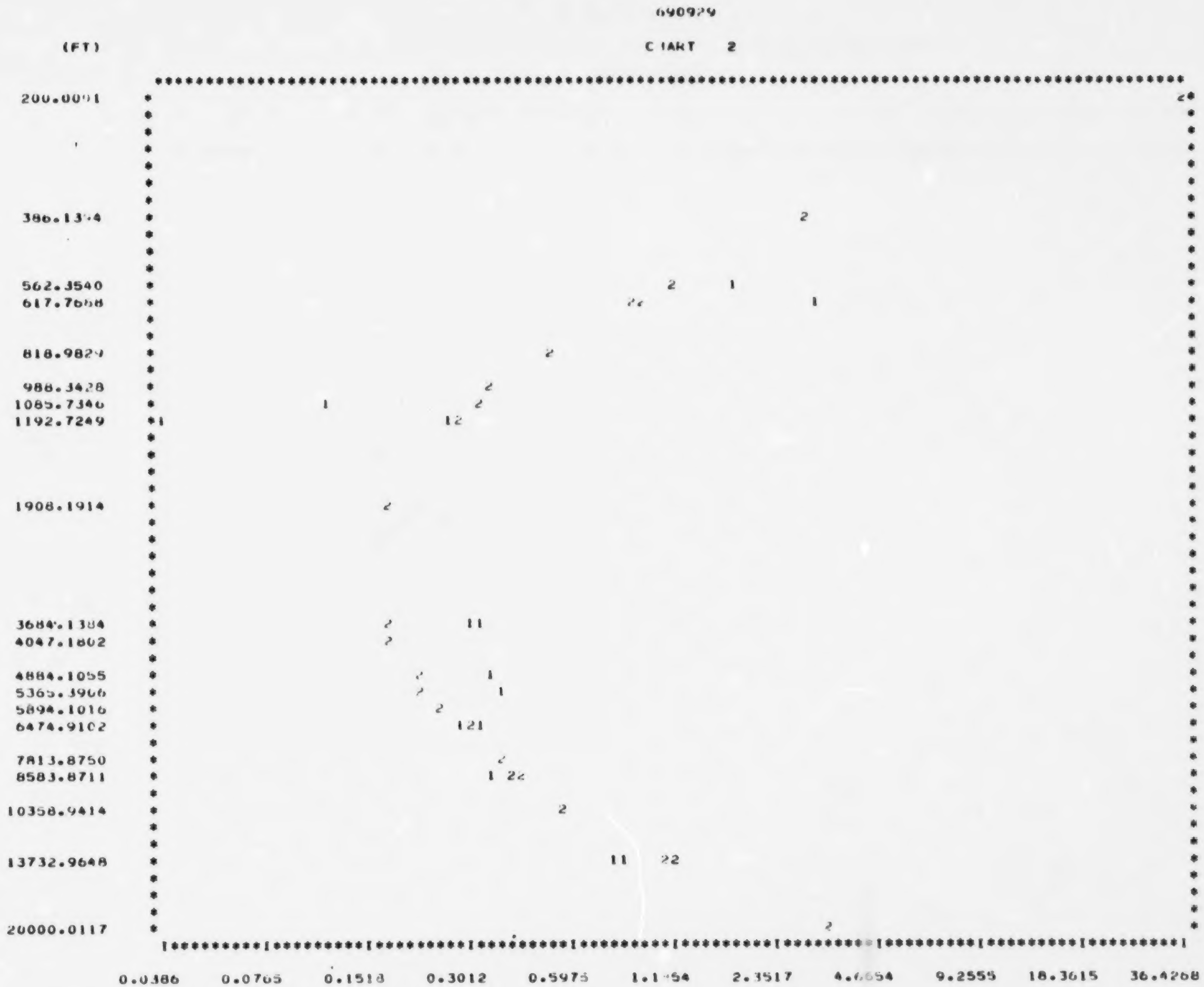


Fig. 104

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.78303
C2=-12.41187
C3= 48.06288

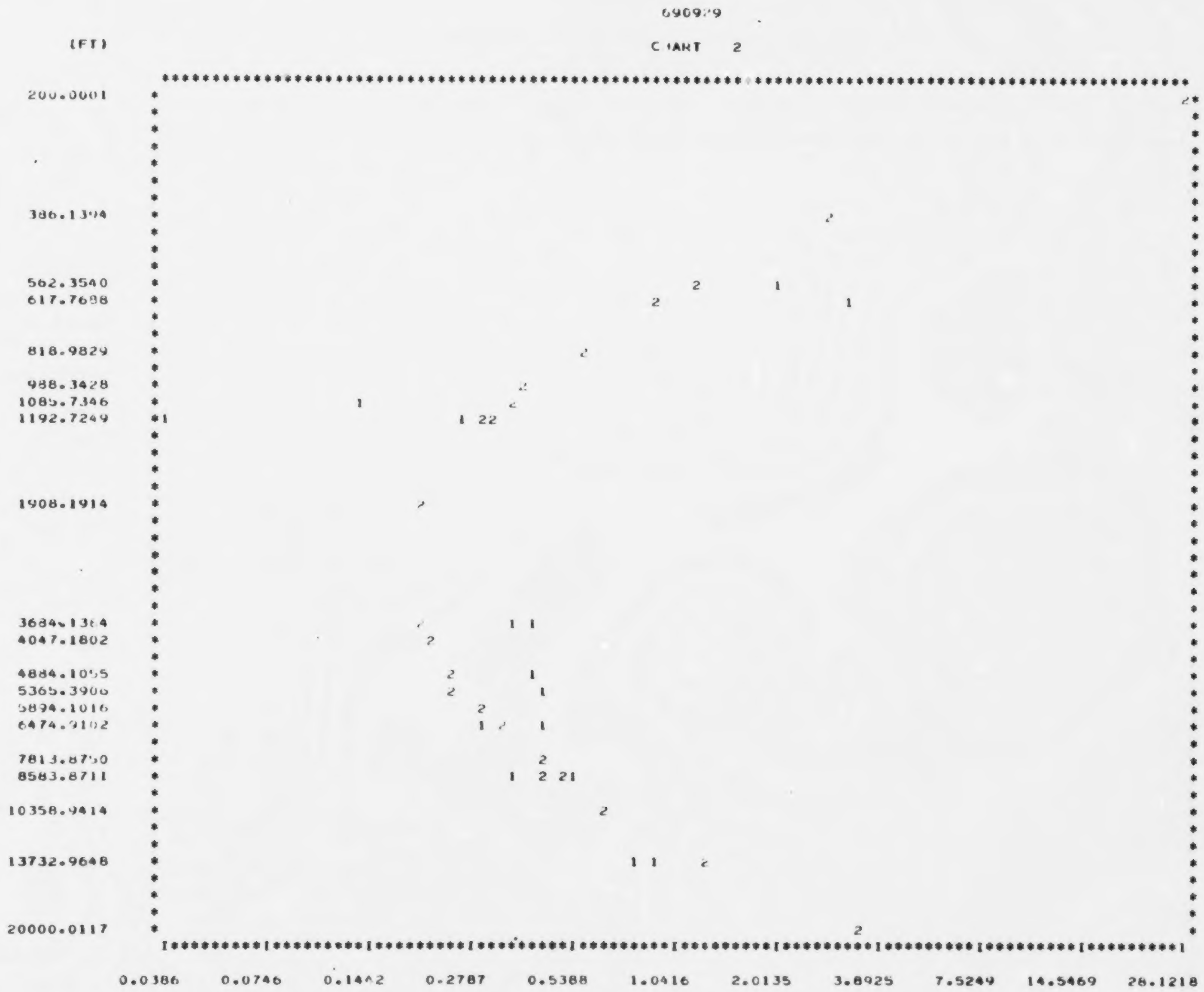


Fig. 105

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.73134
C2=-11.56631
C3= 44.77516

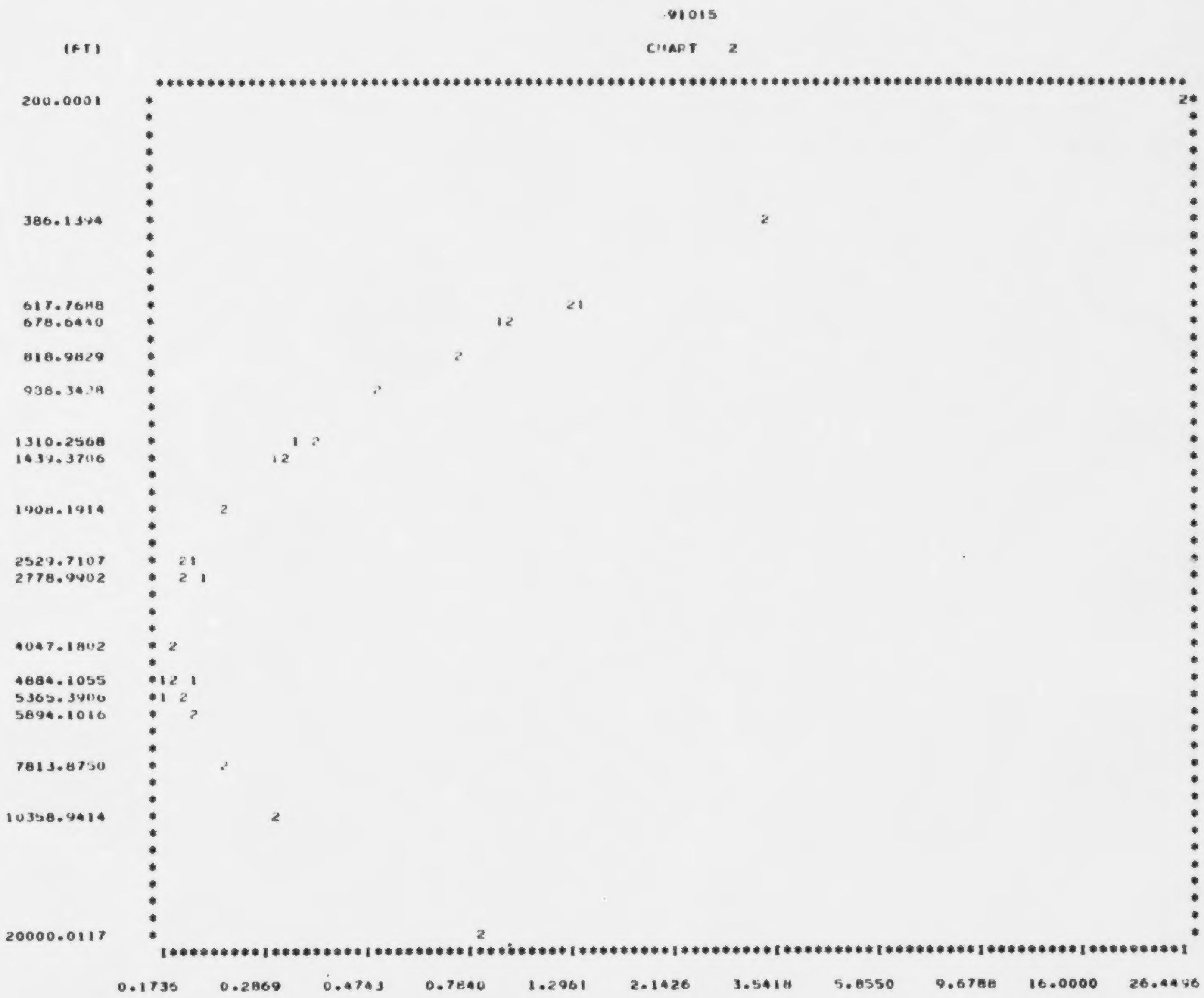


Fig. 106

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.56290
C2= -9.30997
C3= 16.73814

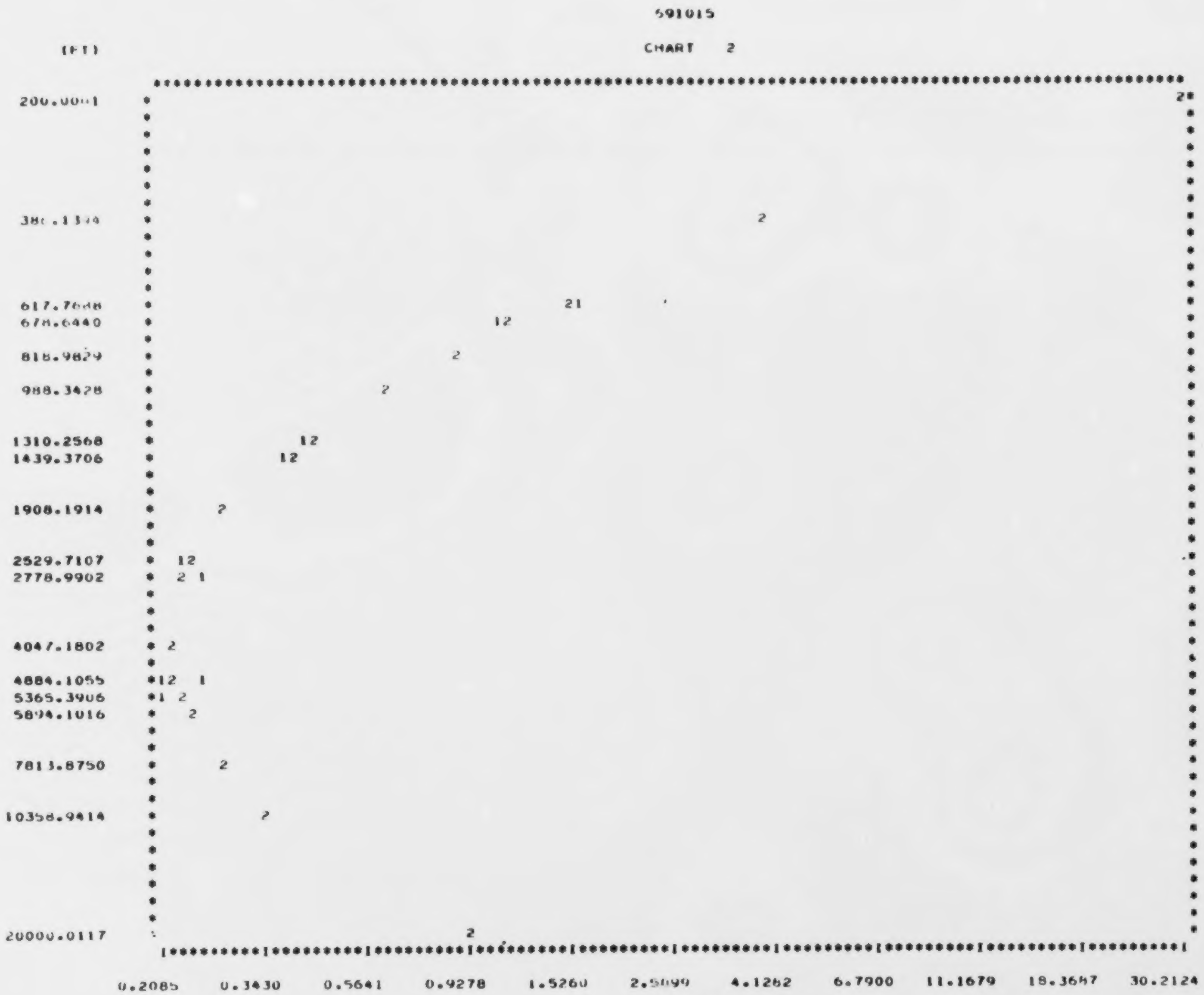


Fig. 107

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.55356
C2= -9.16391
C3= 36.35947

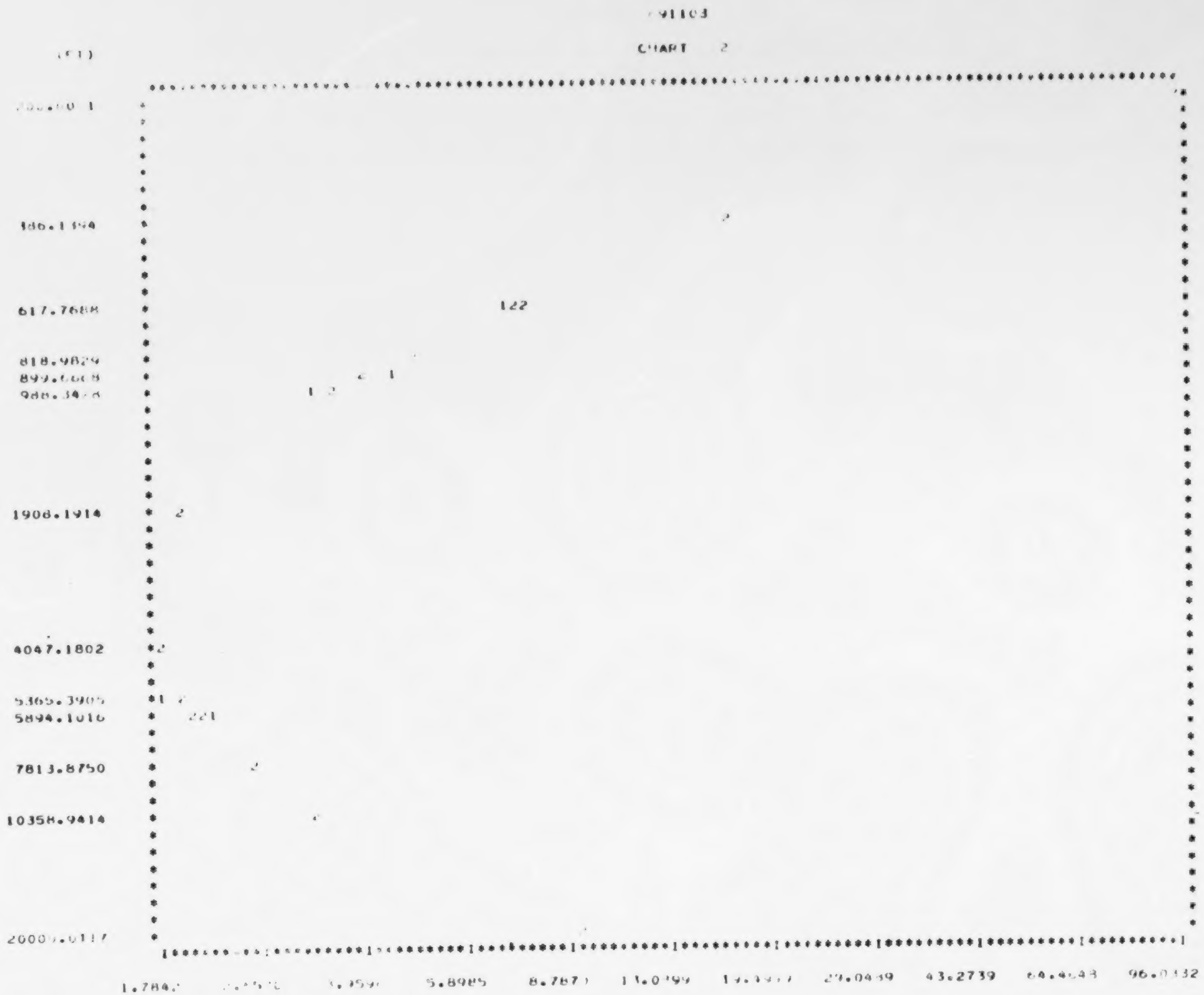


Fig. 108

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= [illegible]
C2= -[illegible]5890
C3= 32.[illegible]

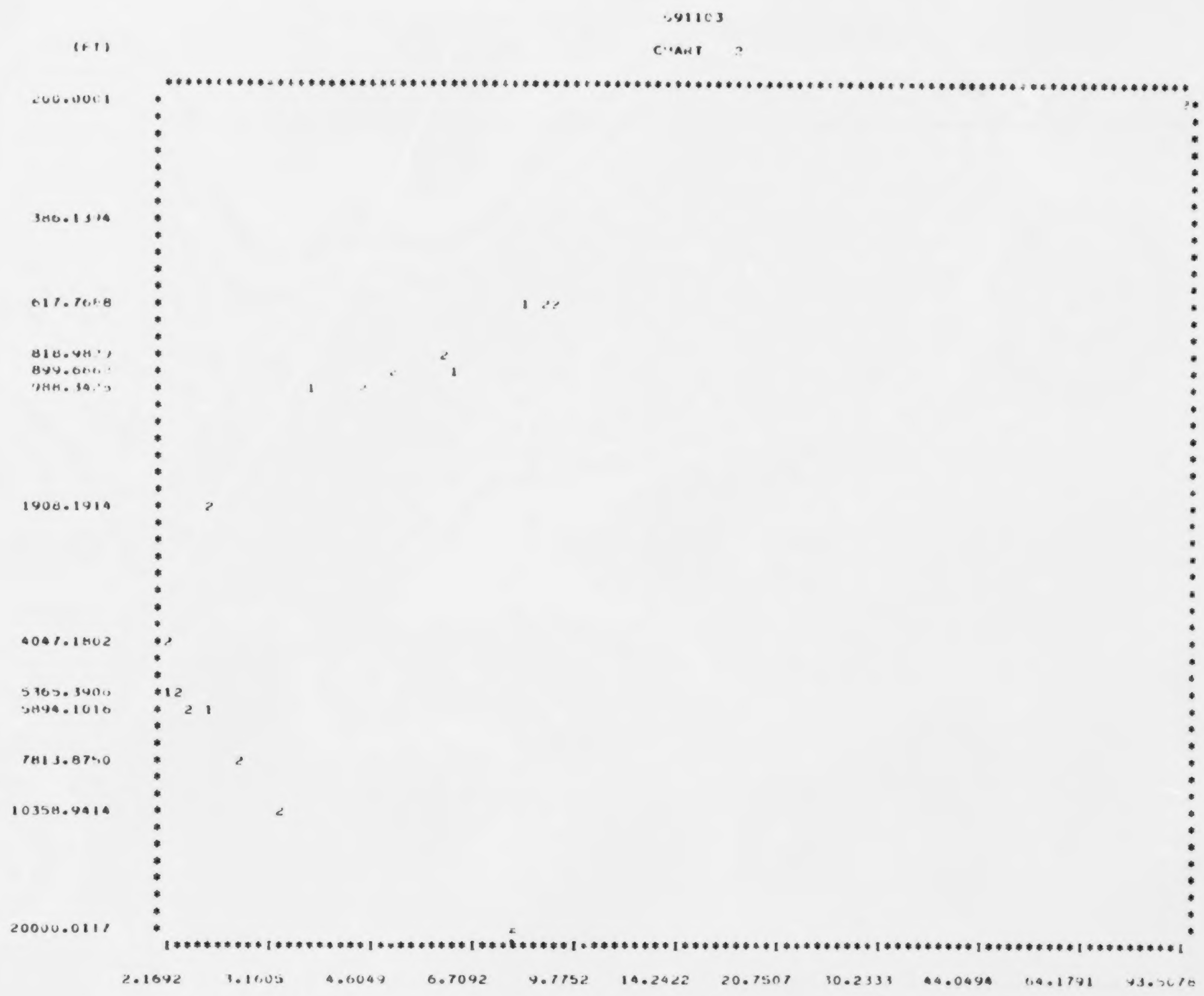


Fig. 109

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.44601
C2= -7.31816
C3= 29.51382

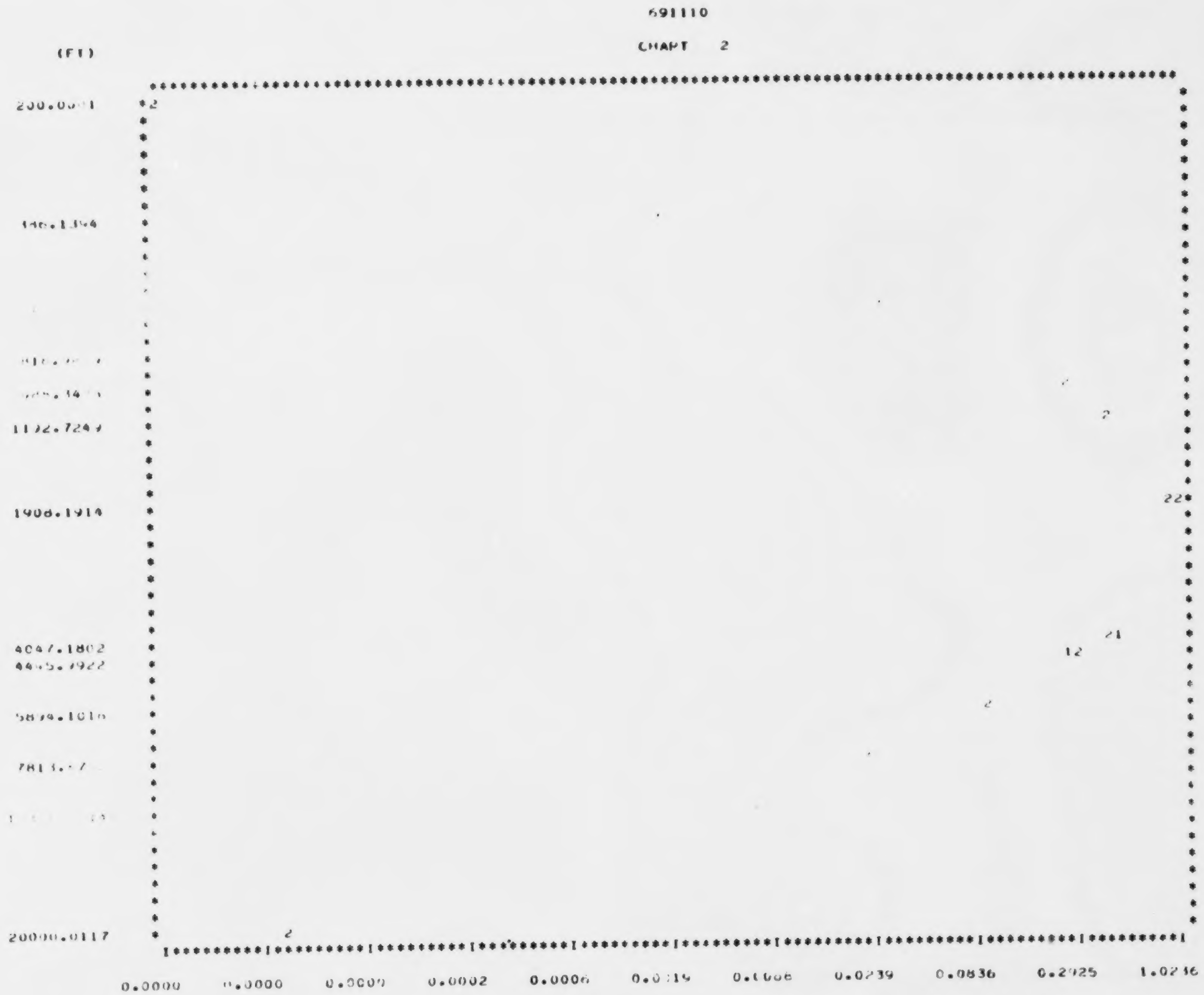


Fig. 110

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION x 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -2.21674
C2= 34.03481
C3=*********

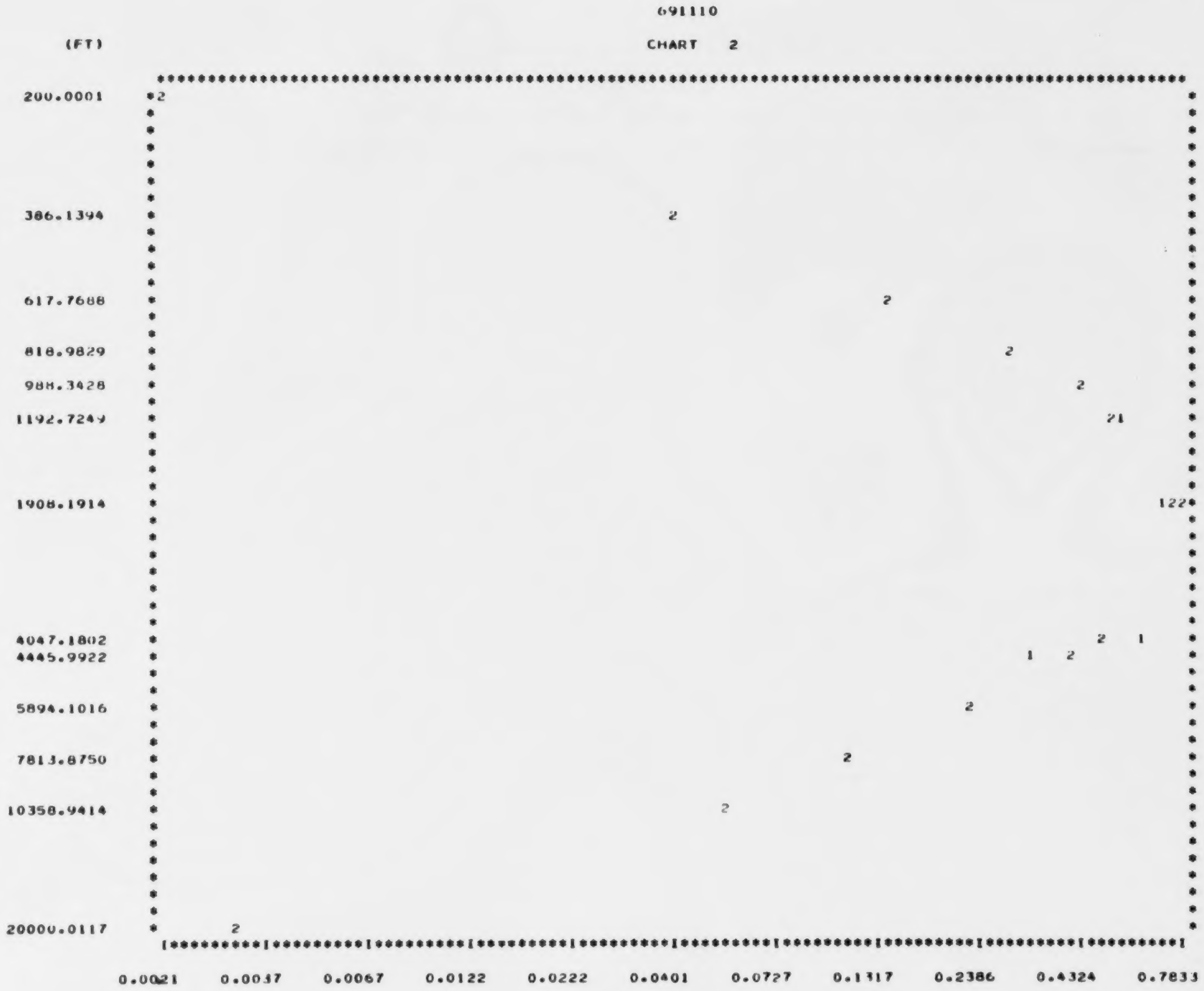


Fig. 111

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -1.07842
C2= 16.49164
C3=-63.20976

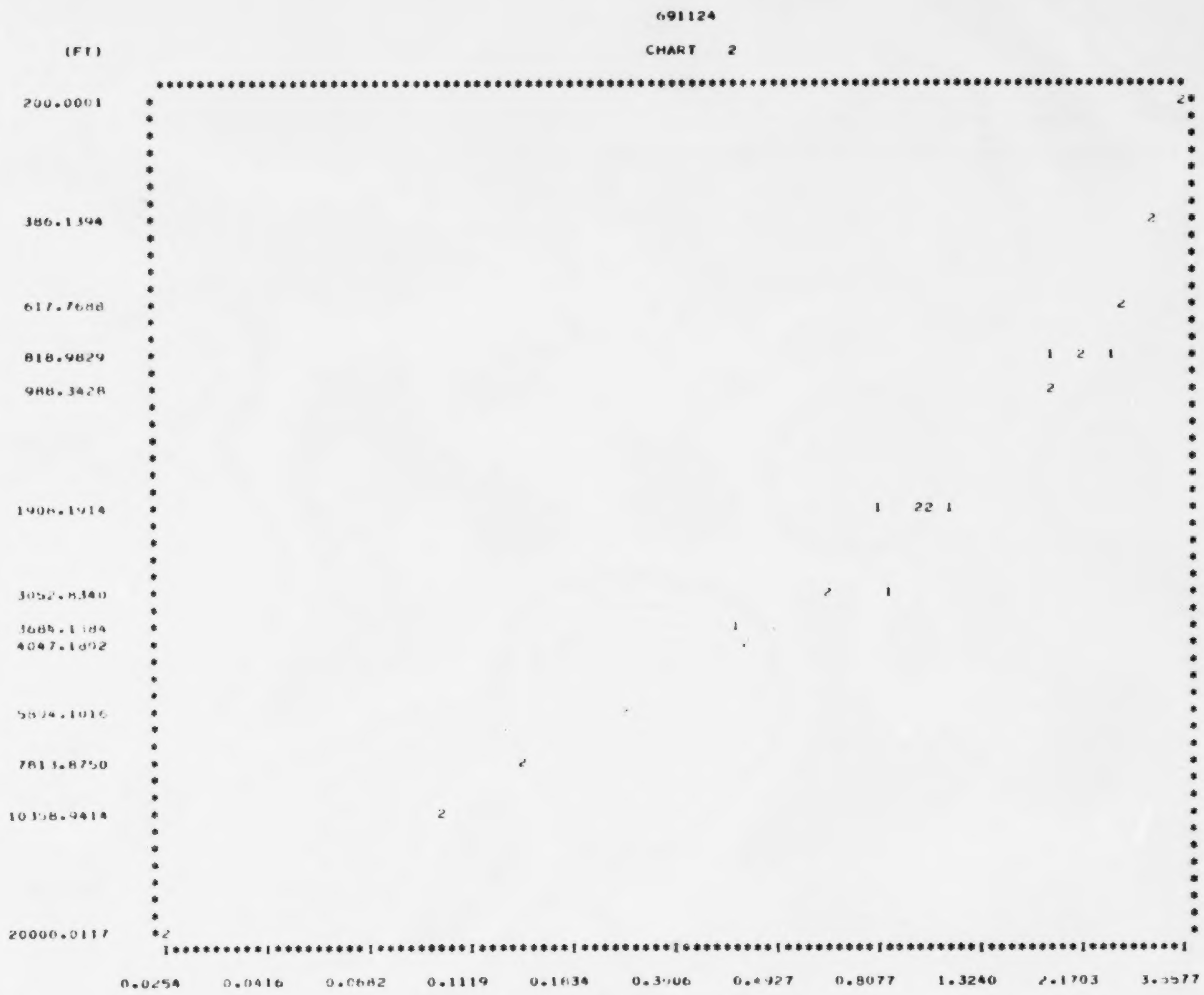


Fig. 112

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.23081
C2= 2.43547
C3= -4.55667

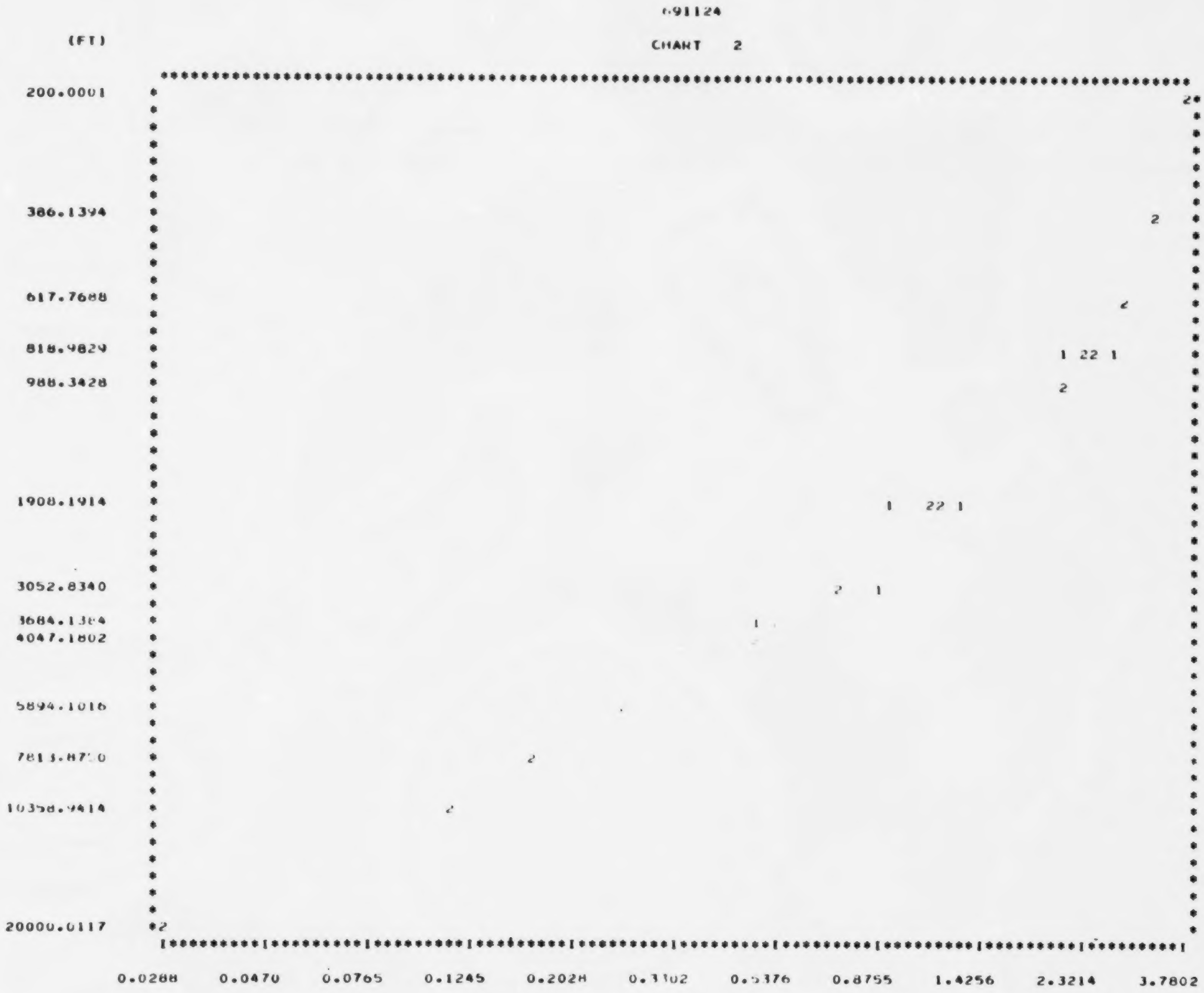


Fig. 113

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.23329
C2= 2.48768
C3= -4.70289

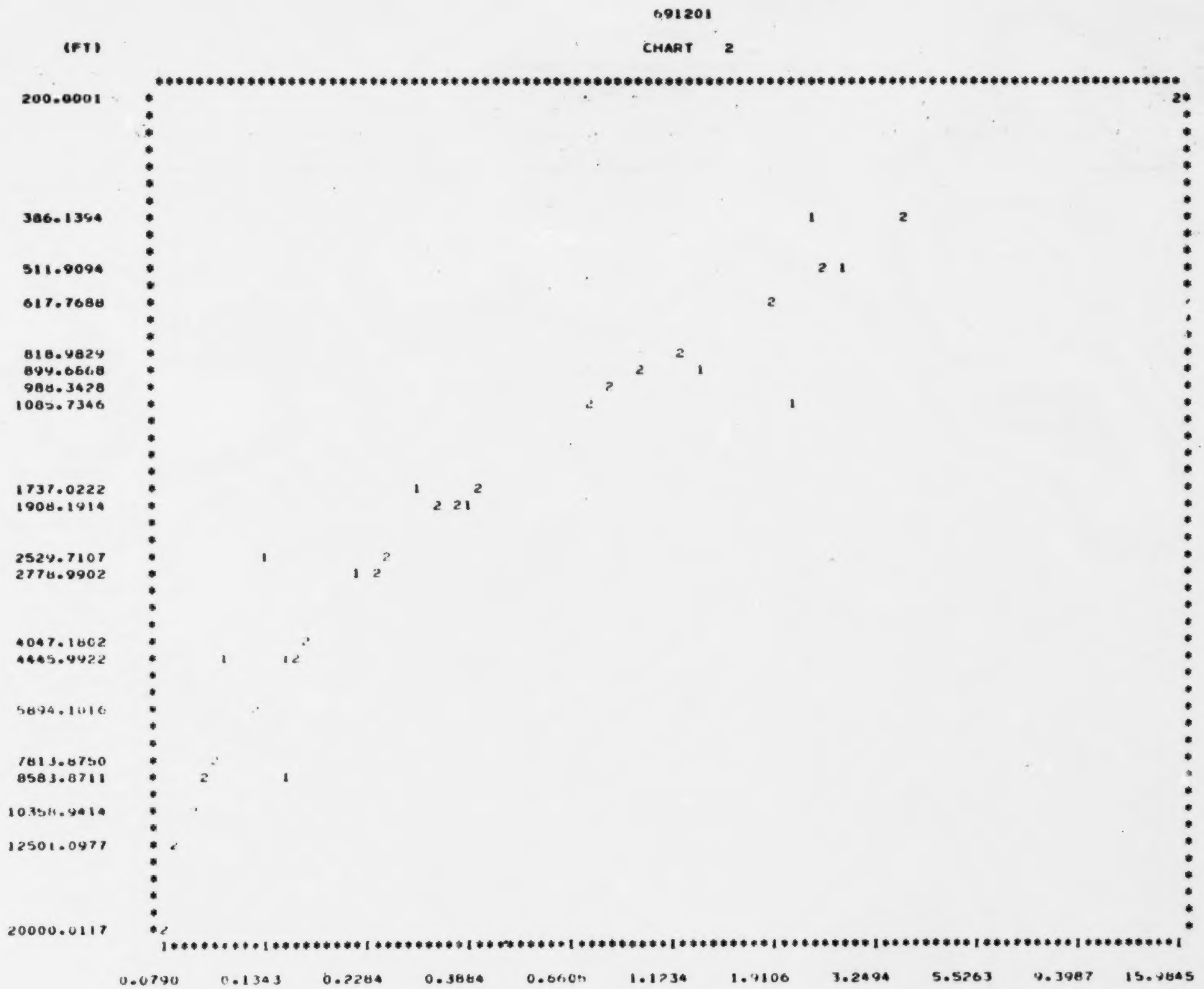


Fig. 114

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.22231
C2= -4.51273
C3= 21.33736

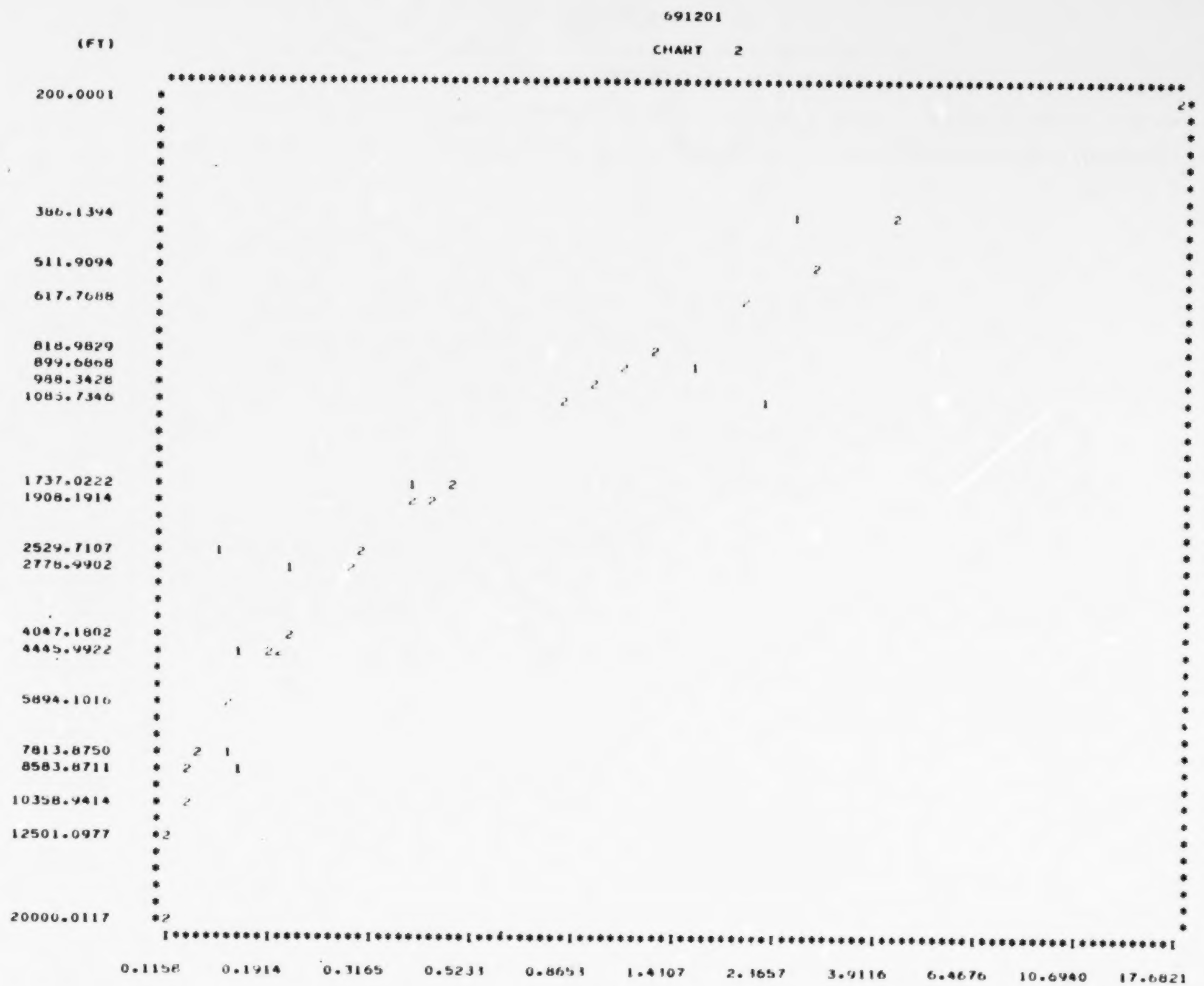


Fig. 115

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.23904
C2= -4.72577
C3= 21.09161

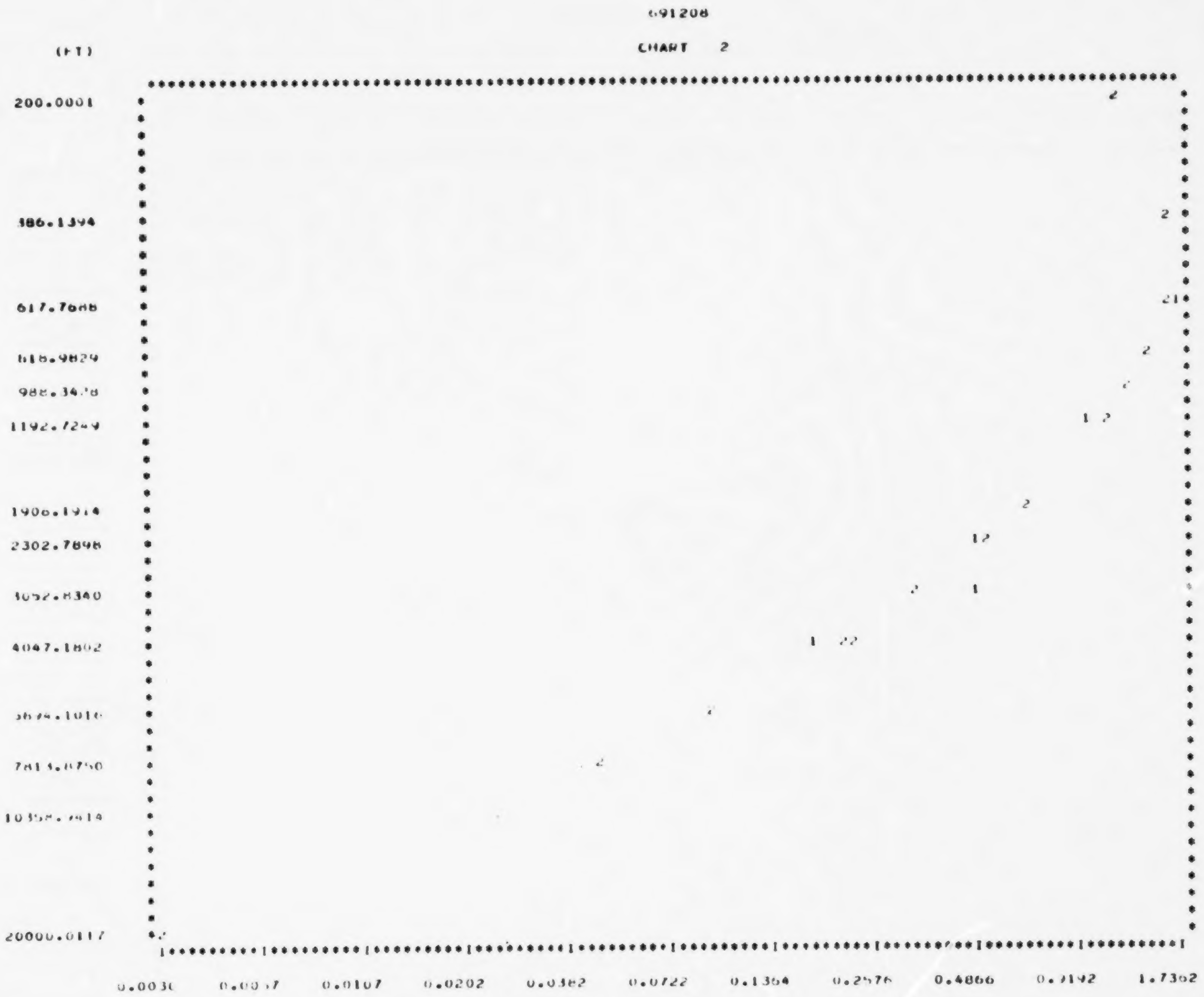


Fig. 116

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.45775
C2= 5.65762
C3=-16.23454

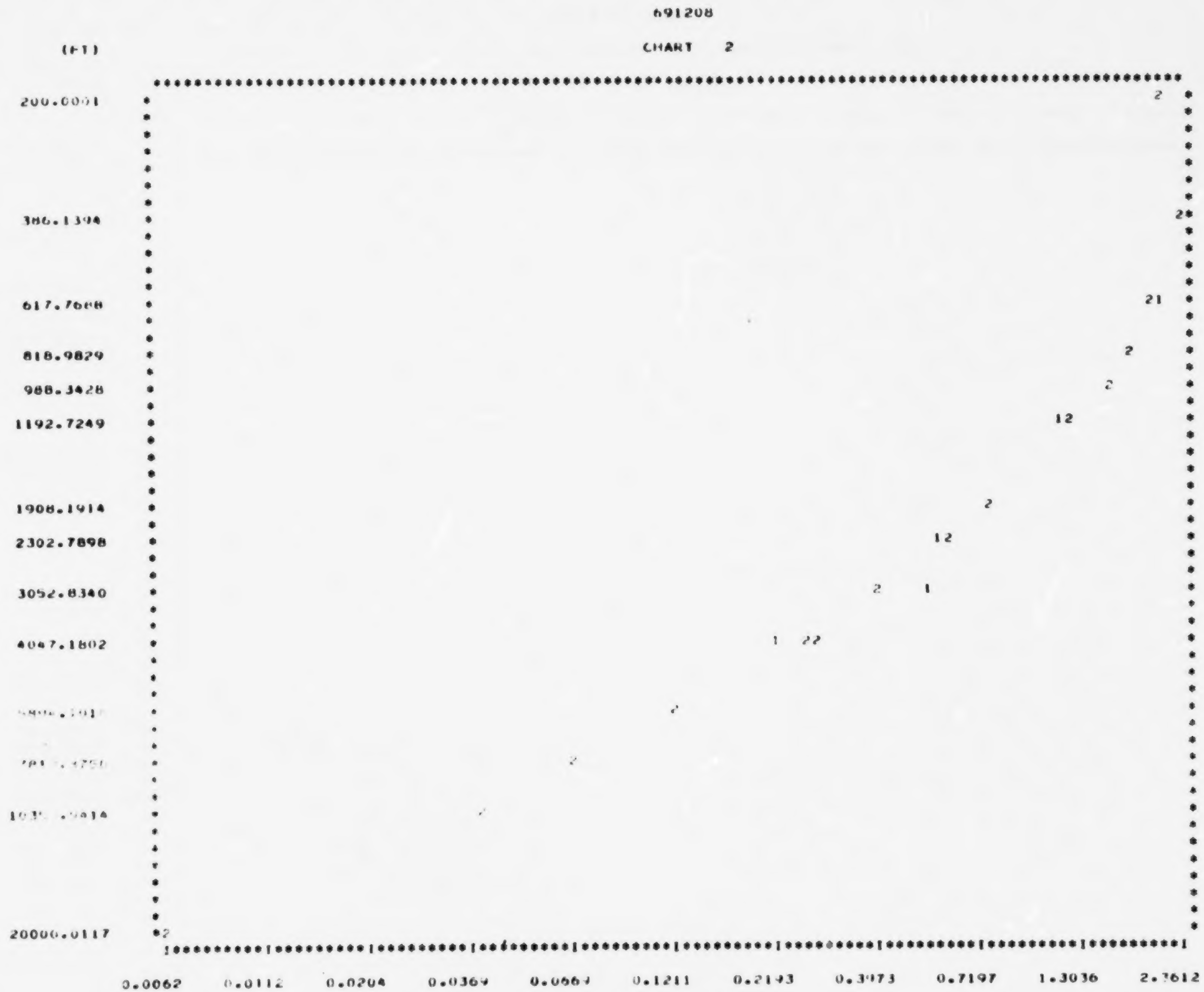


Fig. 117

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.35887
C2= 4.18560
C3=-10.62814

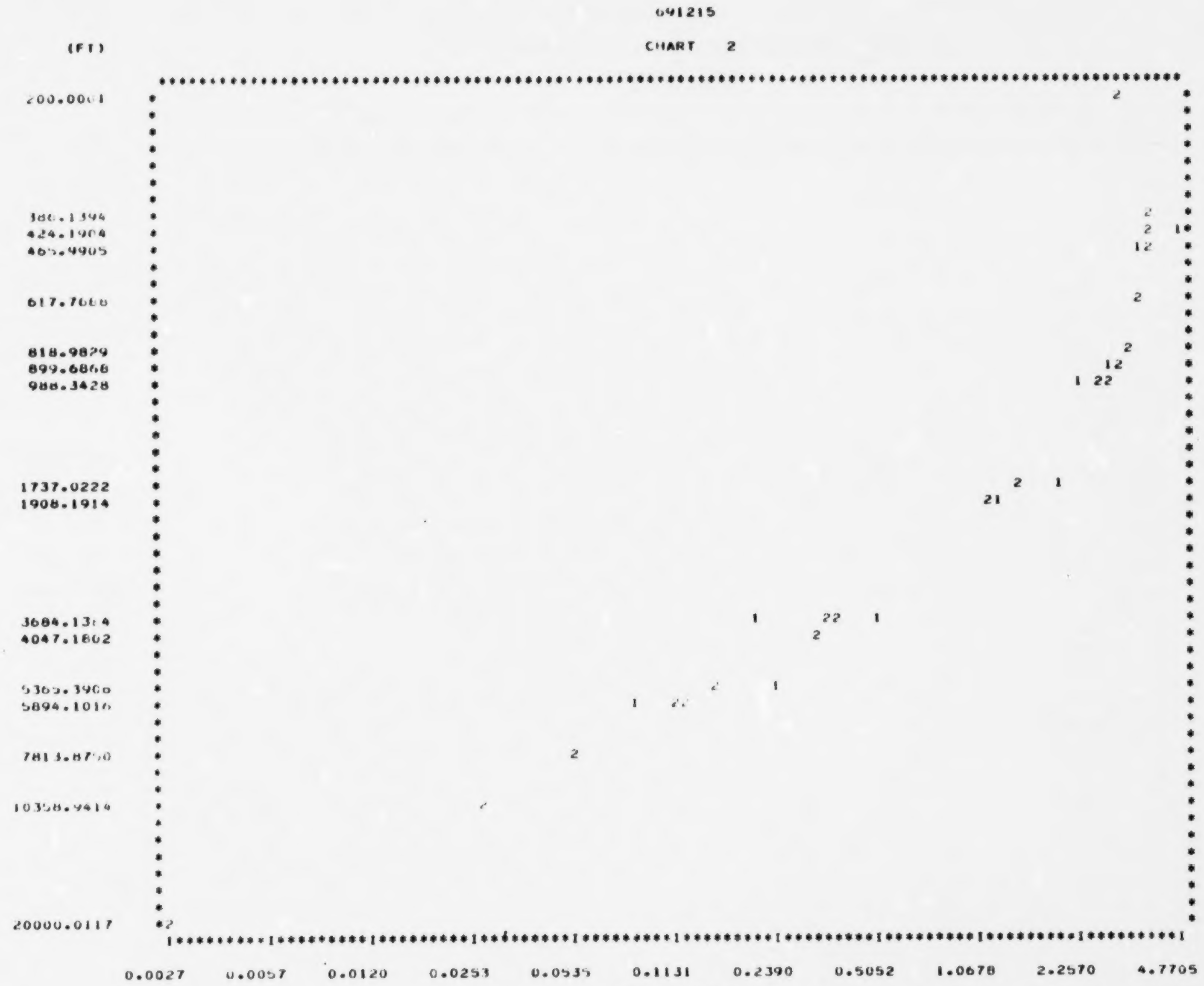


Fig. 118

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.48427
C2= 5.82415
C3=-15.35470

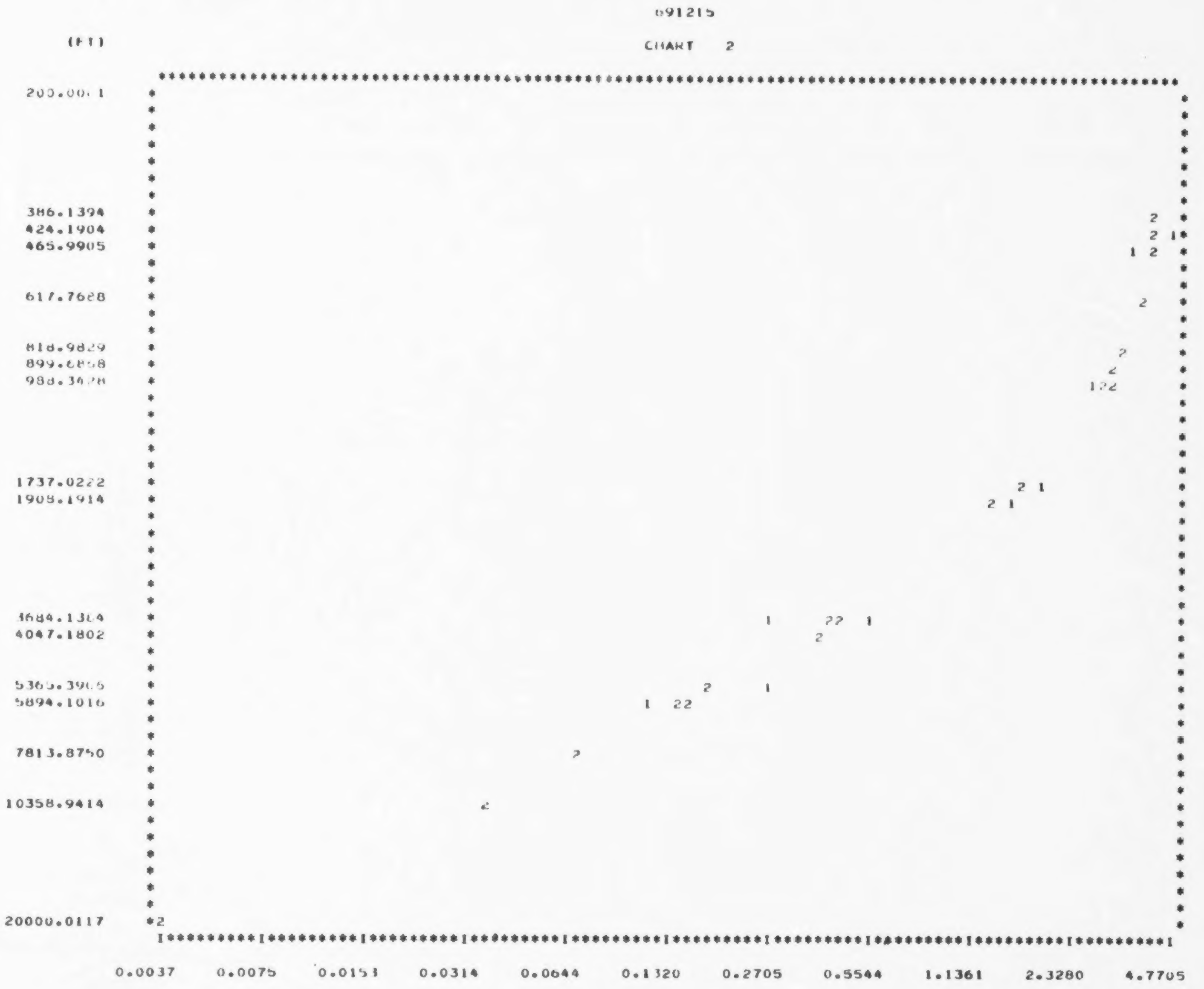


Fig. 119

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.48206
C2= 5.86243
C3=-15.64561

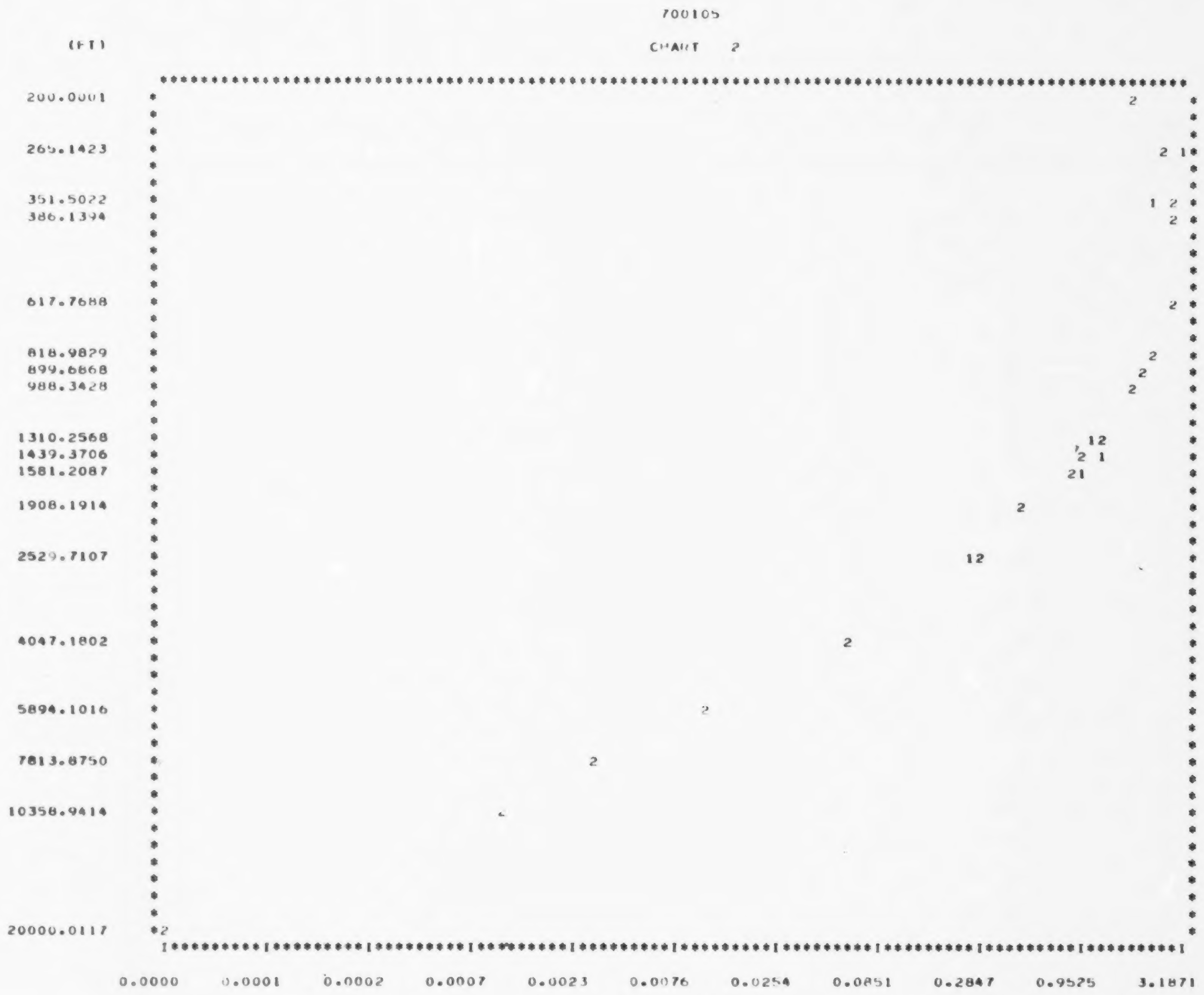


Fig. 120

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.84587
C2= 10.35998
C3=-30.38187

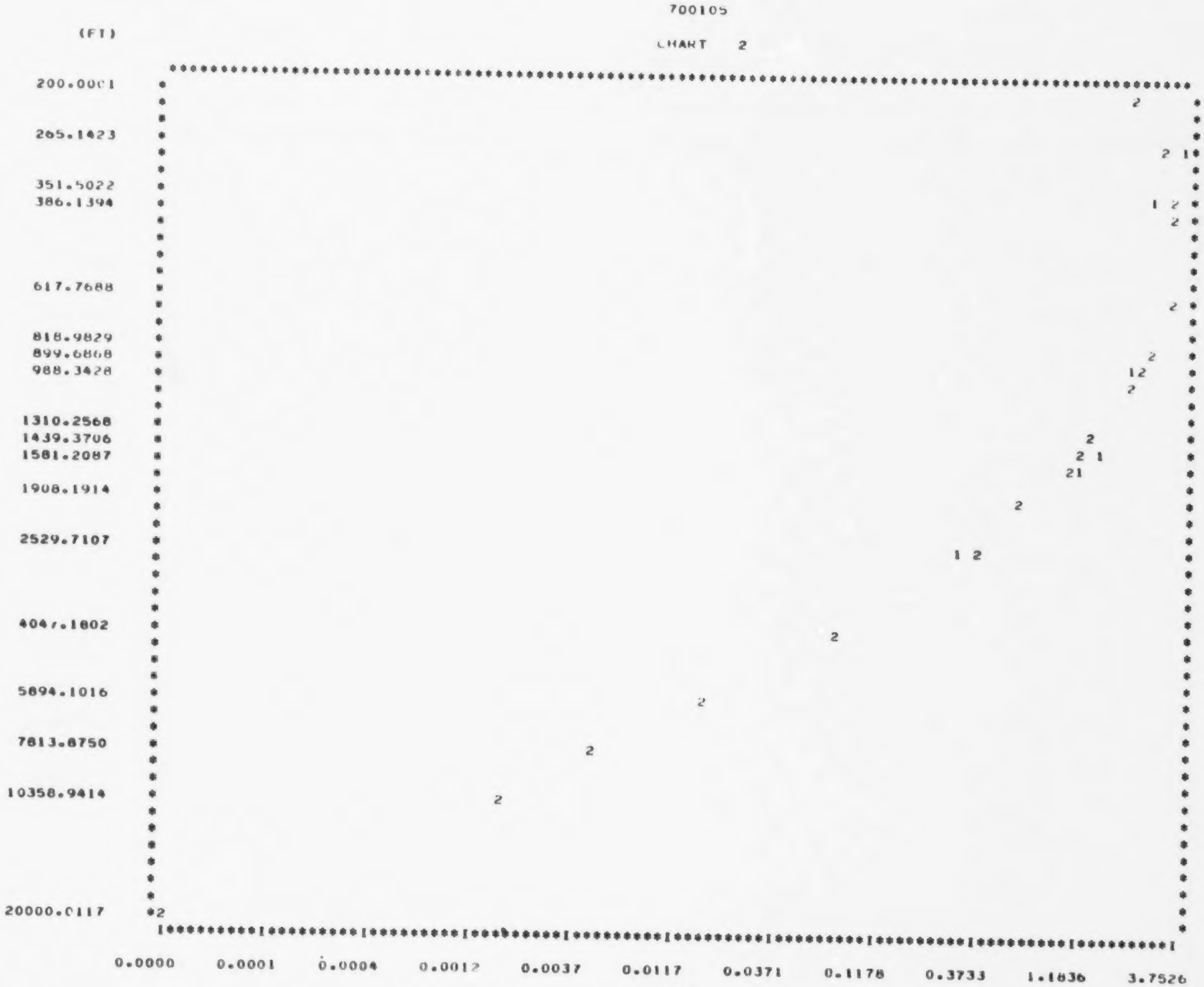


Fig. 121

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.80199
C2= 9.80125
C3=-28.45056

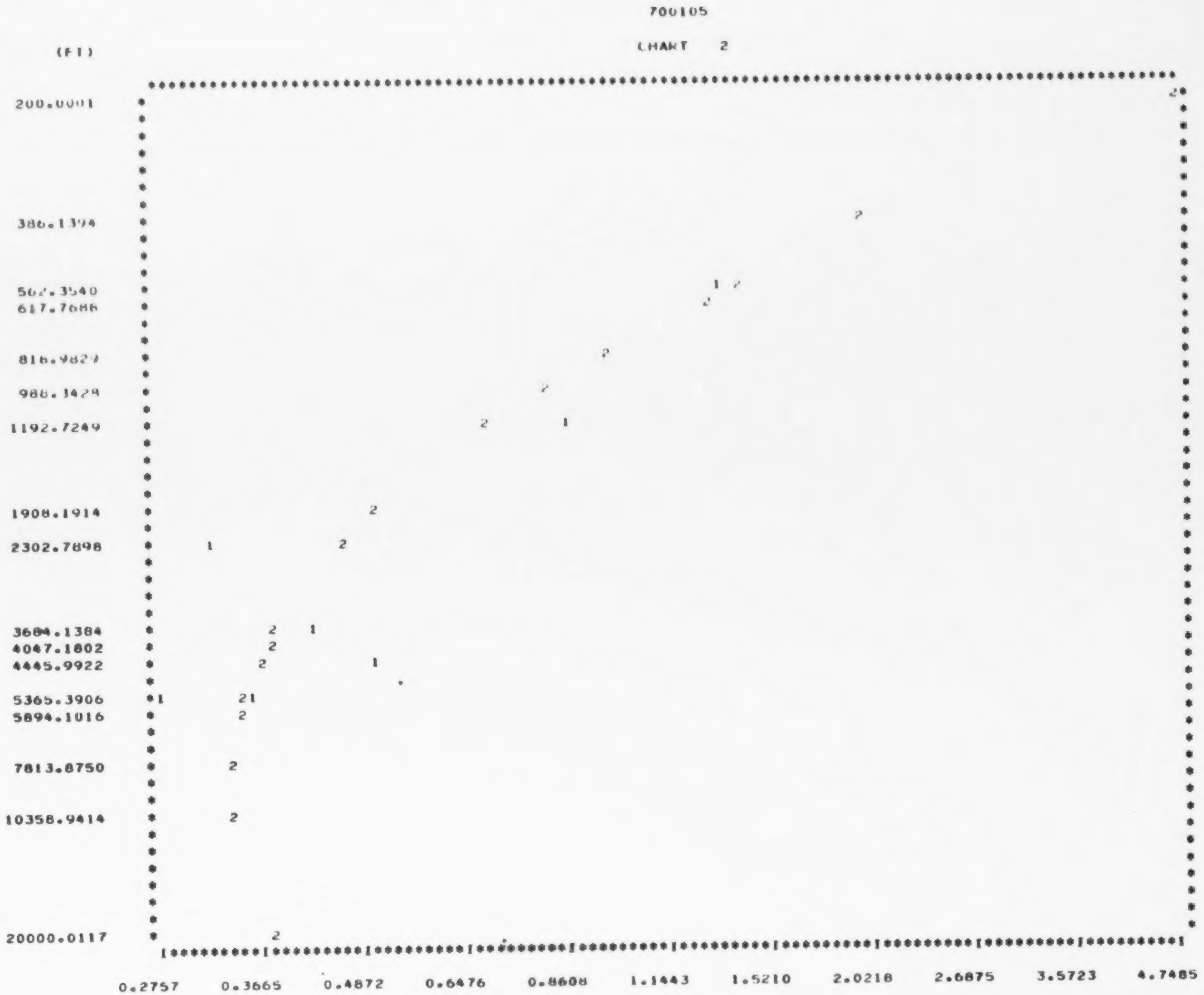


Fig. 122

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.18269
C2= -3.32562
C3= 14.22336

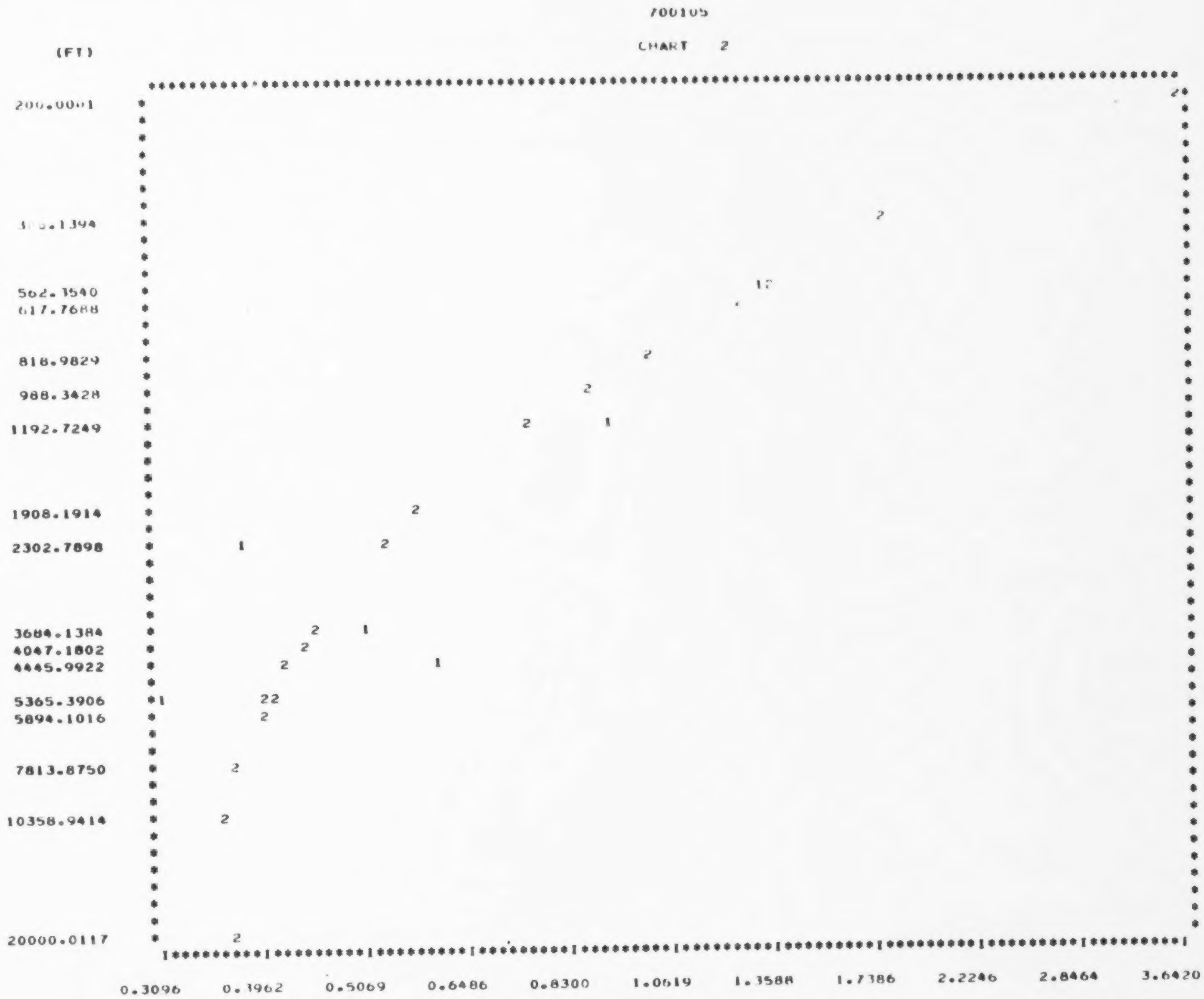


Fig. 123

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1- 0.12848
C2= -2.45038
C3= 10.84270

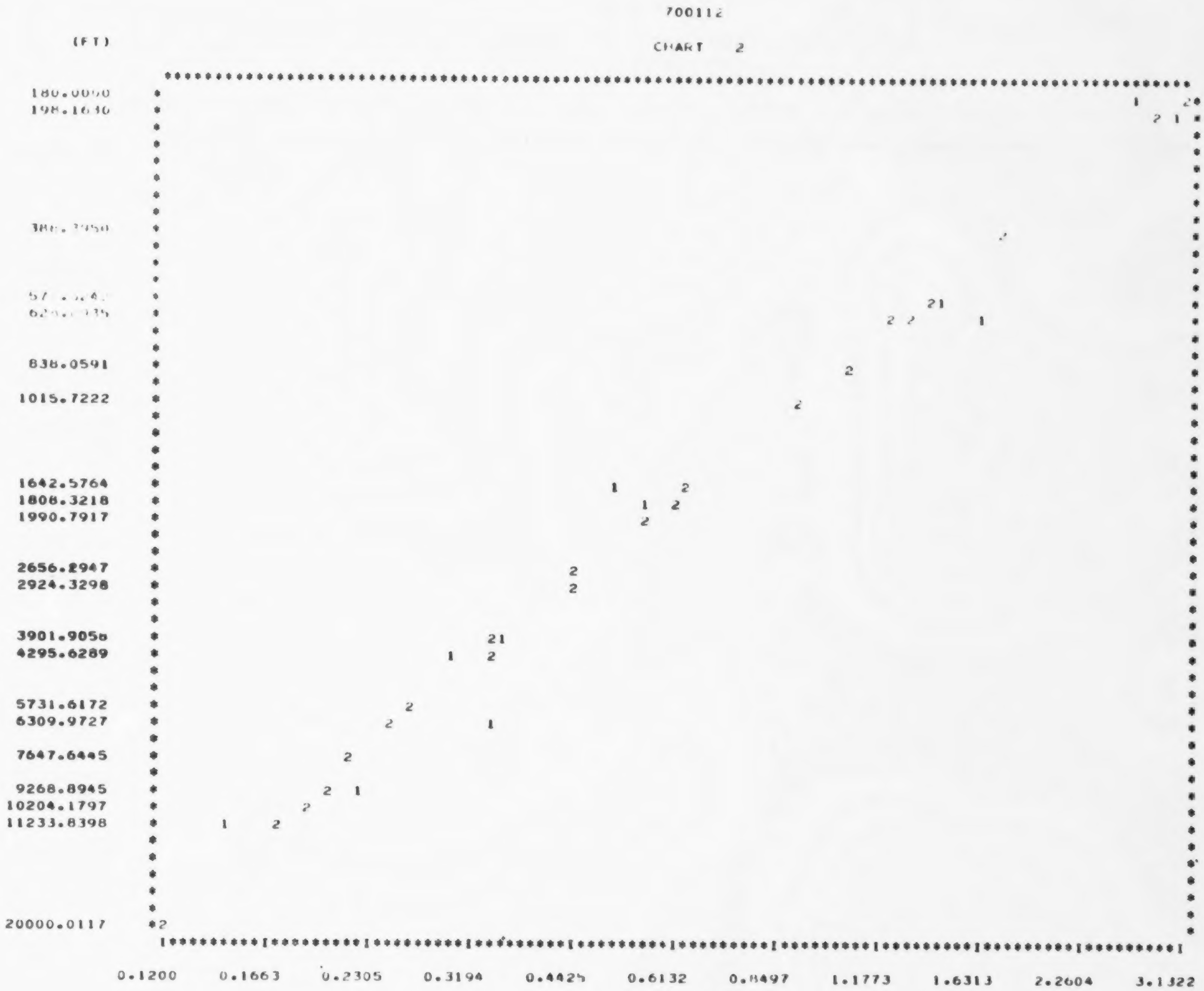


Fig. 124

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1- 0.00688
C2= -0.79630
C3= 4.99697

700112

CHART 2

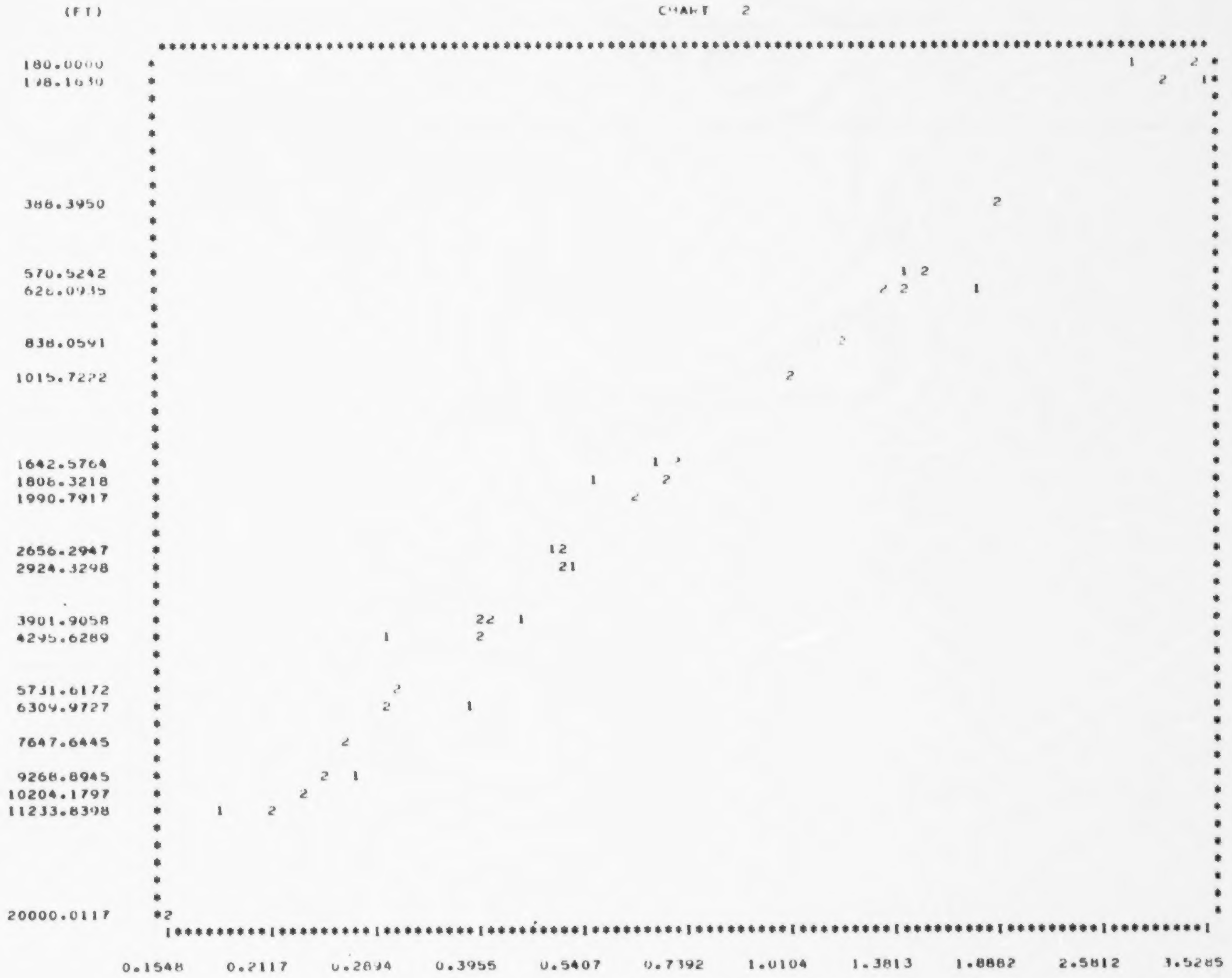


Fig. 125

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.01770
C2= -0.92522
C3= 5.46762

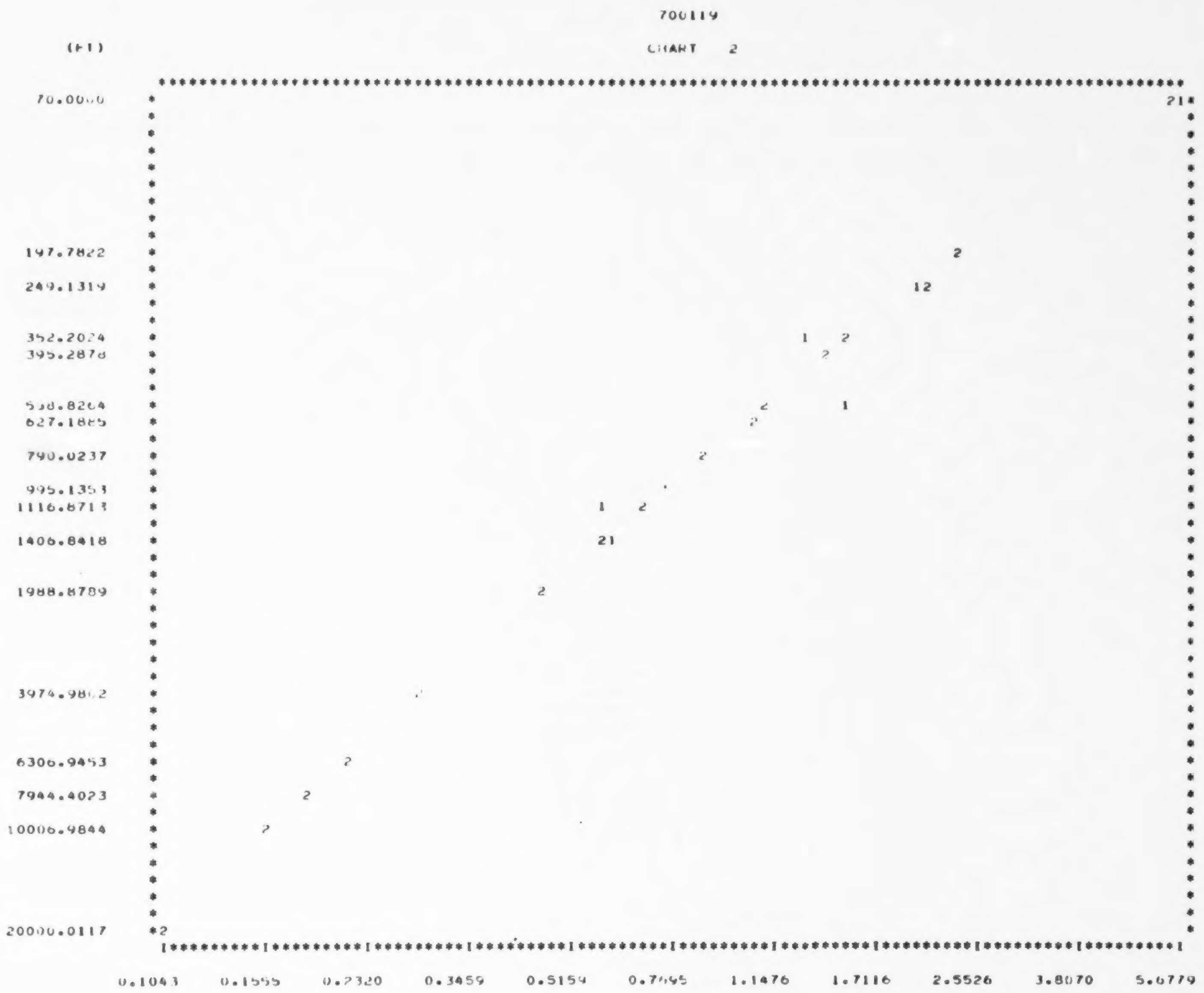


Fig. 126

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.01666
C2= -0.93807
C3= 4.05651

700119

CHART 2

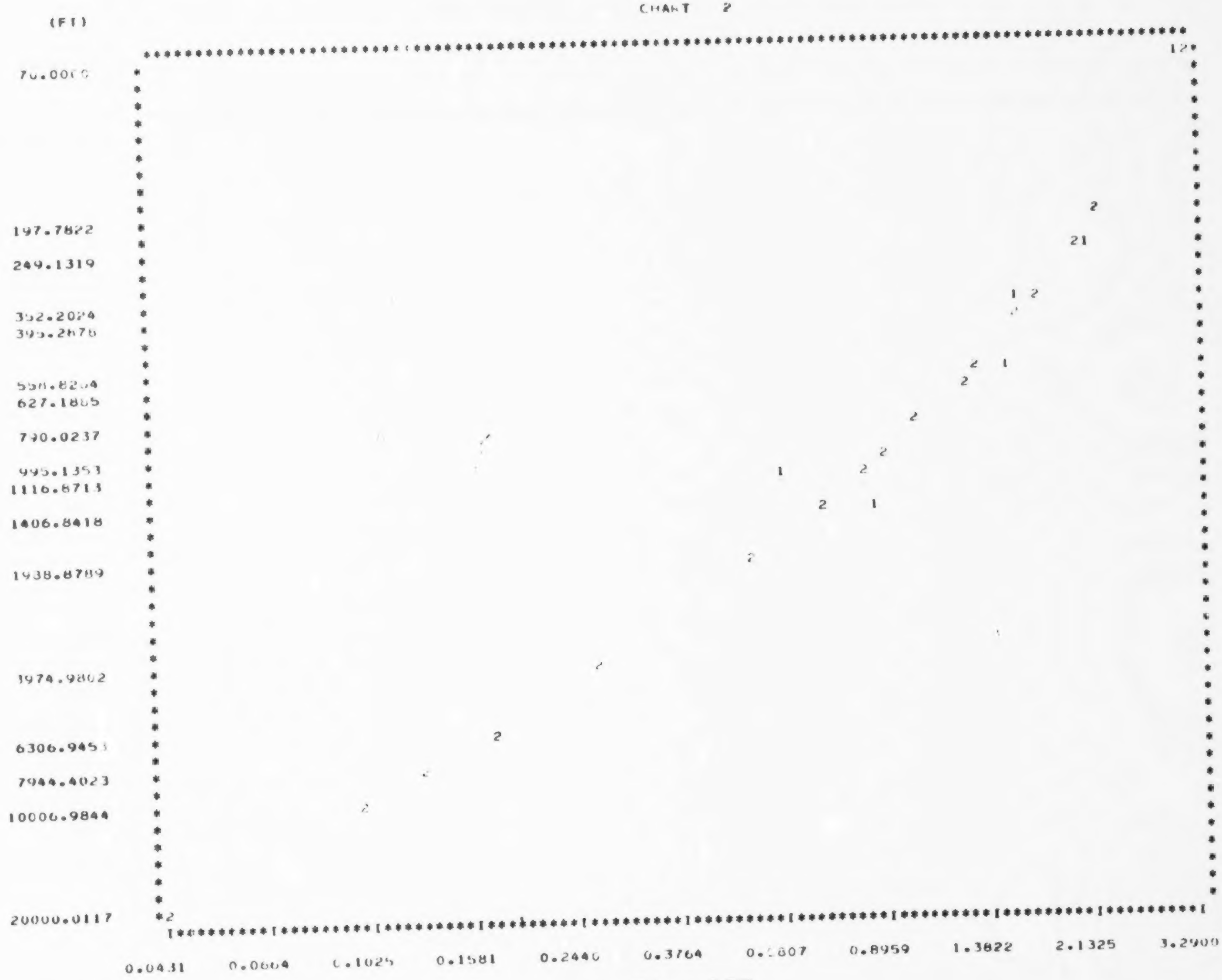


Fig. 127

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.09362
C2= 0.55818
C3= -0.63007

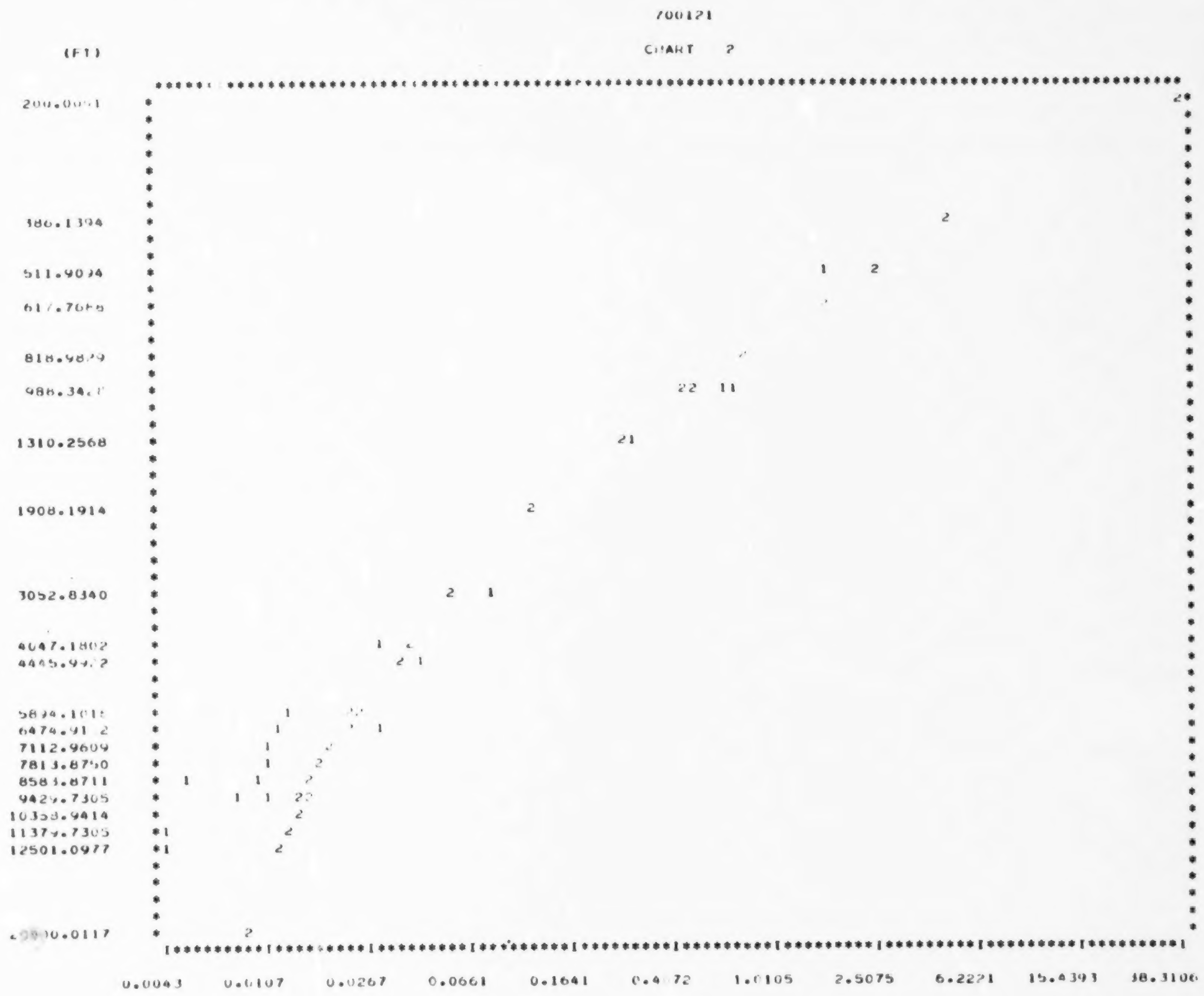


Fig. 128

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.30417
C2= -6.42776
C3= 31.74339

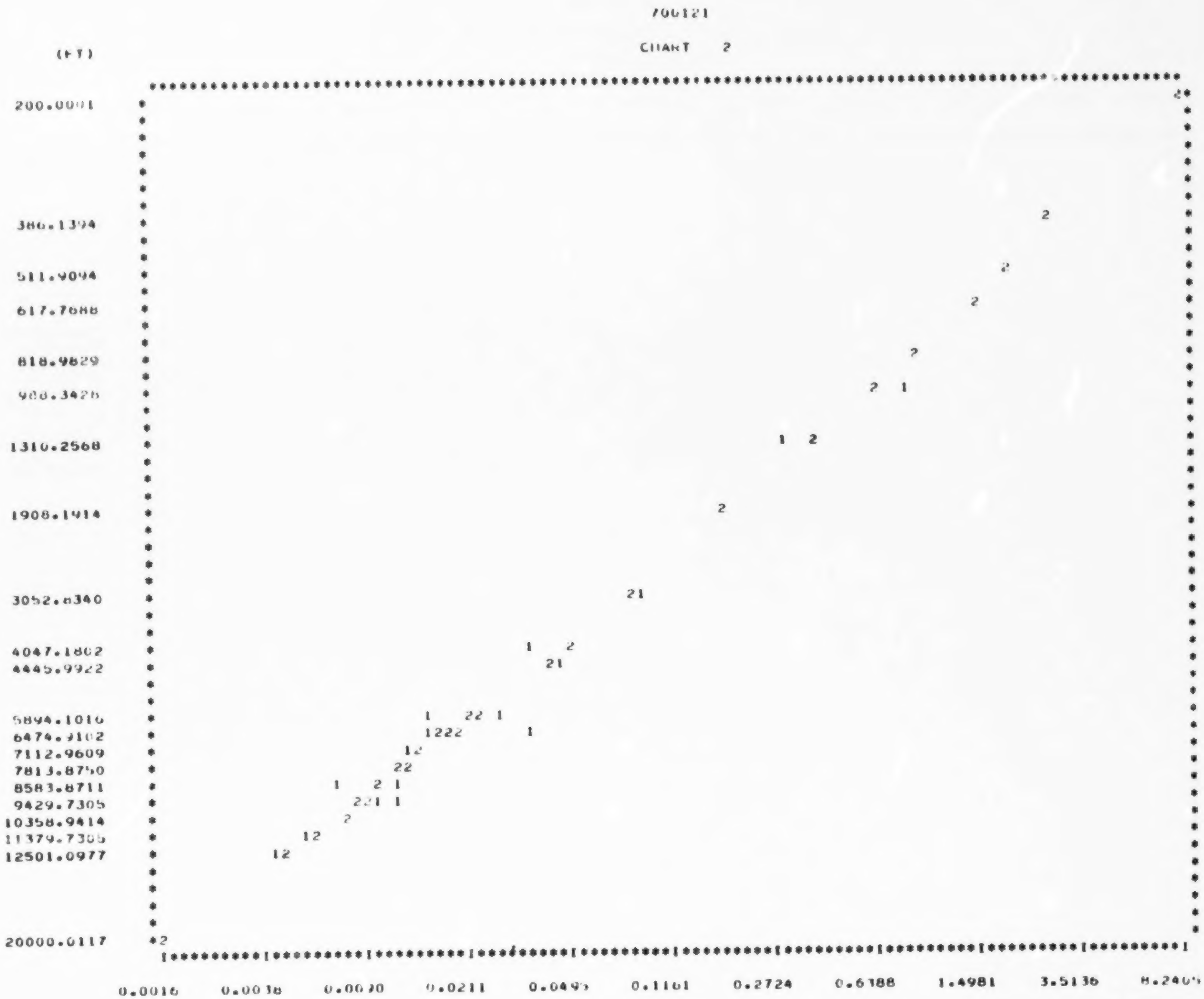


Fig. 129

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.09348
C2= -0.43152
C3= 9.79737

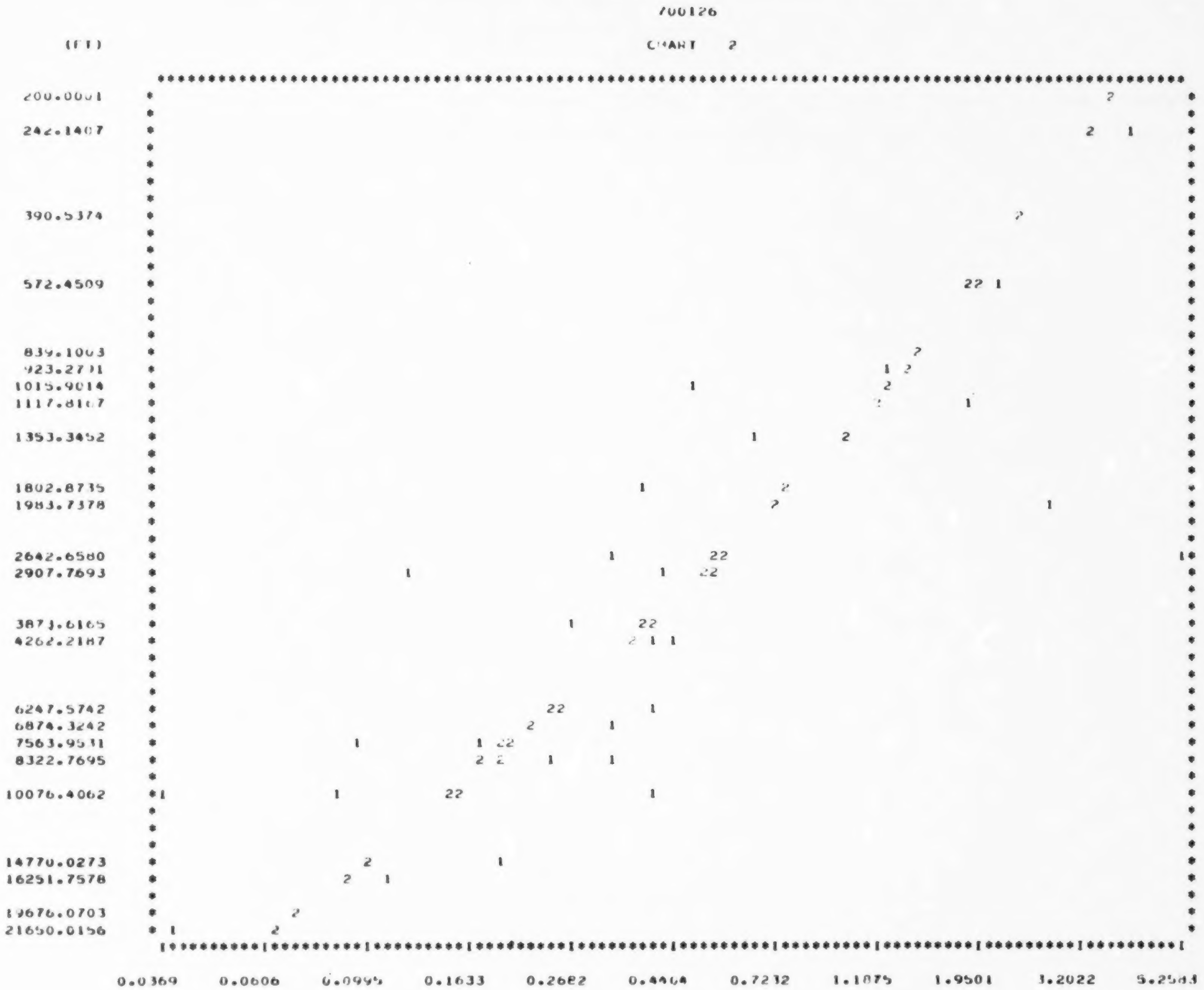


Fig. 130

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.06542
C2= 0.13370
C3= 5.92059

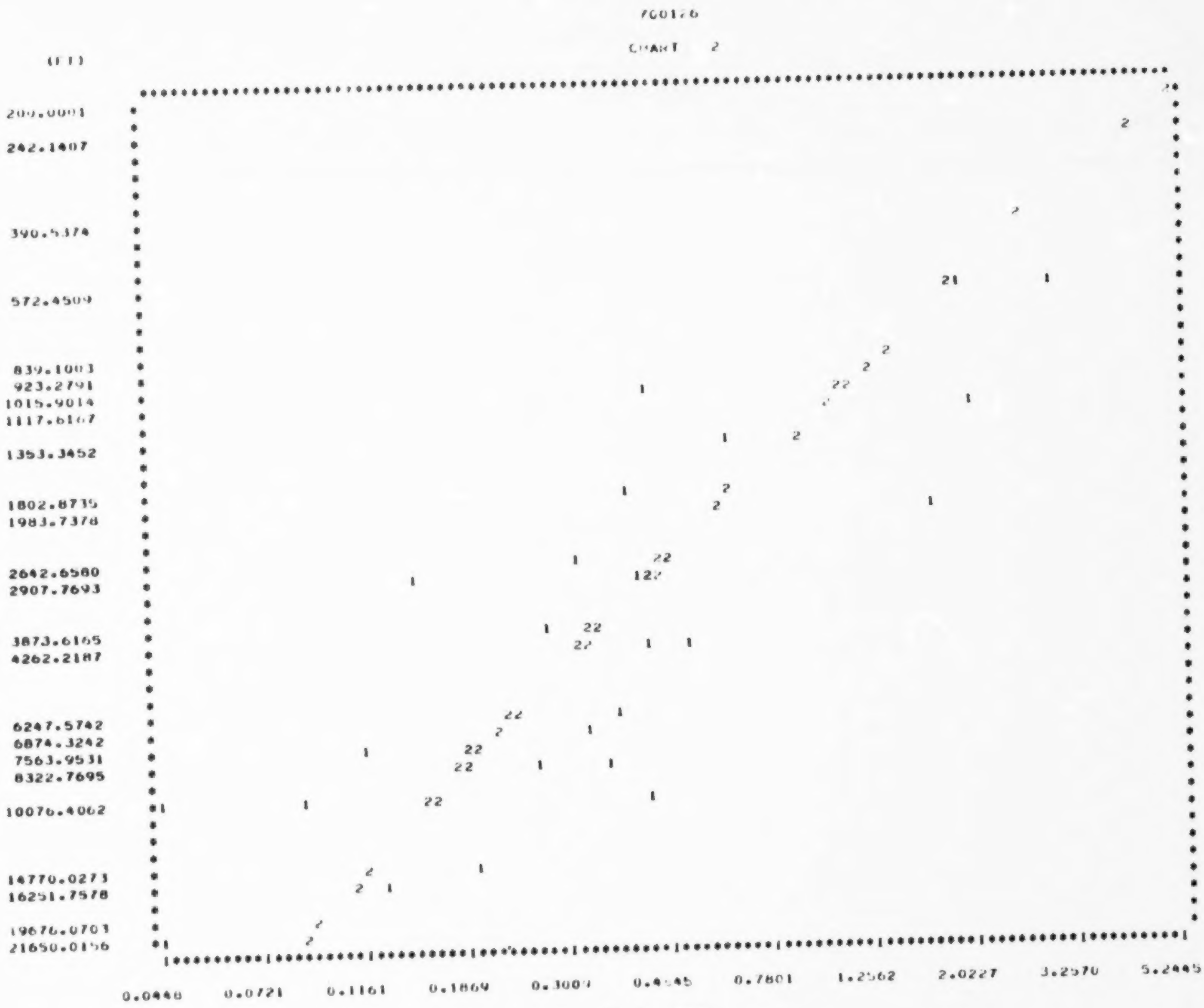


Fig. 131

DISTANCE V.S. SAMPLE TOTAL DILUTION x 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= 0.02281
C2= -1.22009
C3= 10.75494

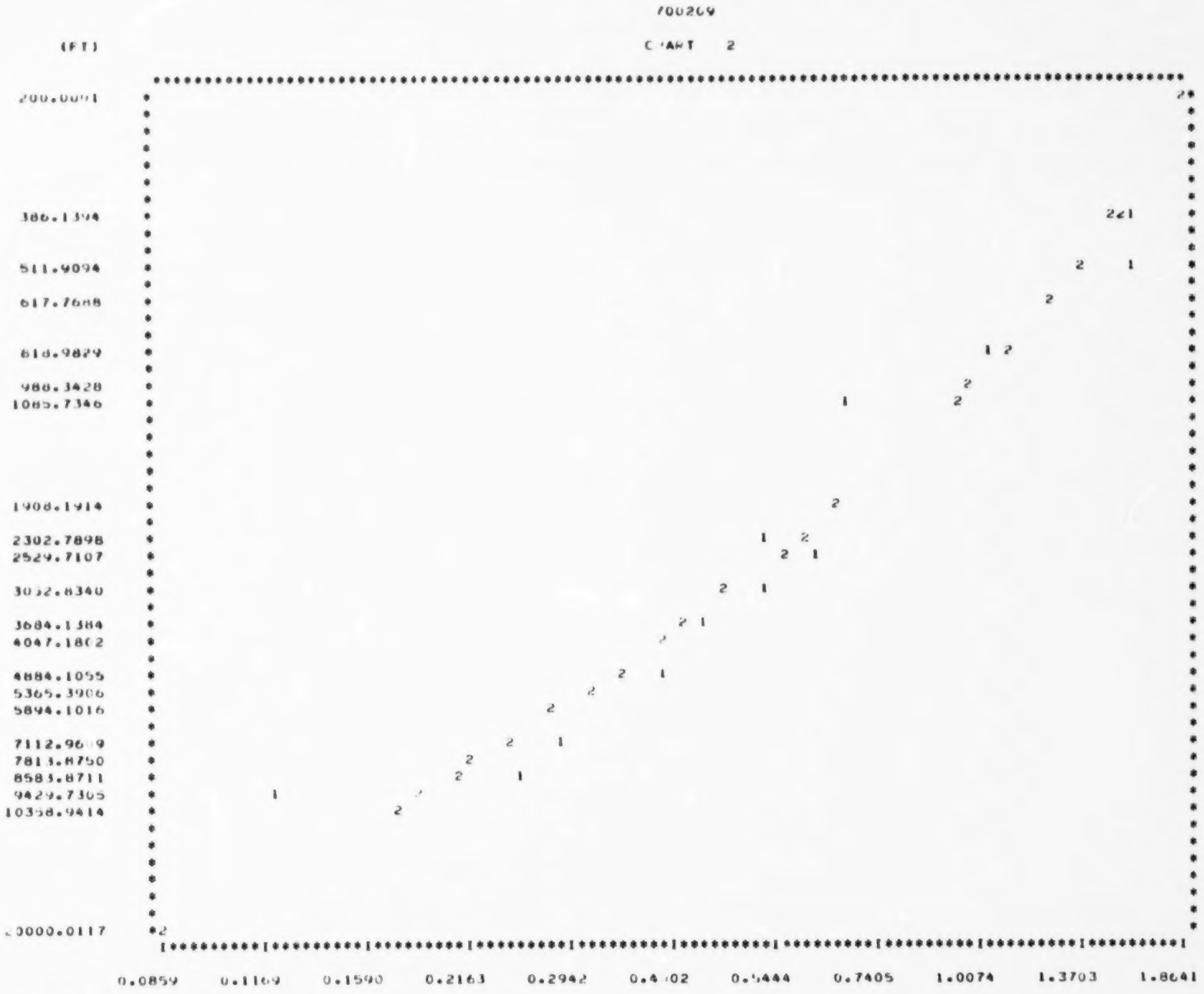


Fig. 132

DISTANCE V.S. GAUSSIAN FIT TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.09461
C2= 0.77011
C3= -0.34728

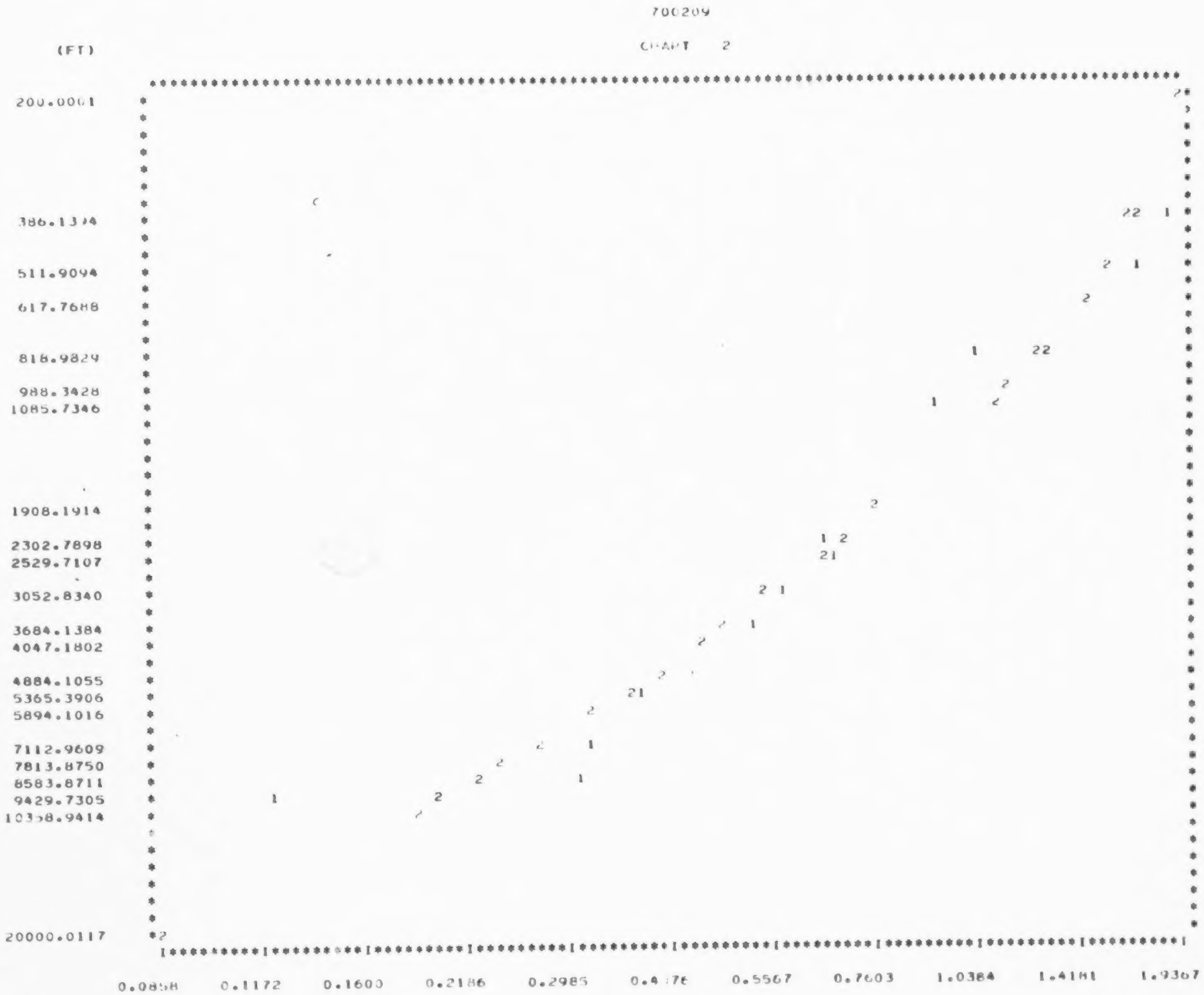


Fig. 133

DISTANCE V.S. SAMPLE TOTAL DILUTION X 1000

(LOG-LOG PLOT)

COEFFICIENTS
C1= -0.12087
C2= 1.16064
C3= -1.64112

the experiments of 8/27/69, 11/24/69, 12/8/69 and 1/21/70 is the dilution sufficient to reach the safe bathing water standard in 20,000 feet. One must then consider bacteria die-off in sea water and determine if the combined effects of dilution and die-off are sufficient to reach the bathing water standard in a reasonable distance from the outfall. The experiments of 1/21/70 and 1/26/70 used one and two gallon slugs respectively of Rhodamine -WT dye injected into the Pompano Lift Station. Experiments of this type yield a large amount of data and can be tracked for large time periods. A consistent feature of the drawings is that experiments with a large number of traverses (data points) give better results. Experiments with few data points can cause the parabolic regression function to become biased and start to increase with distance if the peak concentration of the last traverse increases. In figures where this occurs the fit should be ignored after the last data point.

3) Plume Reconstruction

The most comprehensive way to present the data is to produce a map of surface concentration in the plume. A meaningful map to construct is the contour profile of the state standard for type IIA water, water which is judged safe for body contact. We assume a concentration of 3×10^7 T.C./100 ml at the lift station which is the generally accepted coliform concentration of raw sewage, and we assume that the sewage is diluted in the same way that the dye is diluted. We are thus most interested in the 30,000:1 dilution contour, which dilutes the initial concentration to 1000 T.C./100 ml.

Before we can plot this contour we must smooth out the systematic error in the location of the mean point of the various transects. The actual location of the mean position is biased by the response time of the fluorometry system, mainly due to the fact that it takes several seconds for the sea water to be pumped into the fluorometer.

Thus we first locate the mean positions of each transect, then we fit a second degree polynomial to these locations. This polynomial fit uses the north-south location as the independent variable and fits the east-west variable. This choice is based on the fact that the north-south distance tends to change more during the course of an experiment.

Once the mean positions are fitted we then artificially reposition each transect to have its mean value on the fitted line. We re-position the transect by keeping the x position (north-south) fixed and changing the y position.

The contours are calculated by taking each transect and calculating the position along the transect where 30,000:1 dilution of the initial concentration would occur. Since this dilution for normal dye pumping rates is below the sensitivity of the fluorometer some form of extrapolation is necessary. We have chosen to extrapolate both by using the Gaussian fit analysis and the sample fit analysis.

This double analysis is performed because it is felt that there is considerable advantage in providing two points of view which represent different extremes. The Gaussian fit method will always estimate a larger cross-stream standard deviation than will the sample fit. The sample fit peak concentration, however, will be larger than the Gaussian fit peak concentration. Thus, the Gaussian fit plume contour will be wider but shorter, whereas the sample fit will be longer and narrower. When the transit yields data which is peaked and of a general Gaussian form the two methods give nearly identical results.

4) Natural Bacteria Die-off

We introduce the effect of bacterial die-off by the method of Stewart et al (1969). If one neglects diffusion in the downstream direction (x) one finds

$$\rho_B(x,y,z) = \frac{Re^{-\lambda x/U}}{\pi U \sigma_z(x)\sigma_y(x)} e^{-\frac{1}{2}(y^2/\sigma_y{}^2 + z^2/\sigma_z{}^2} \quad (21)$$

$\frac{1}{\lambda}$ = time for bacteria to die off to $\frac{1}{e}$ of their original concentration.

Putnam in the Stewart (1969) study established two values of λ, one representative of winter die-off, the other representative of summer die-off.

λ_1 = .31/hour (winter)

λ_2 = 1.55/hour (summer)

These two values of λ are used to decrease the peak concentration as a function of downstream distance, and contours are calculated and plotted which take die-off into account.

It should be noted that this method of calculating die-off will underestimate the bacteria concentration because of dispersion along the stream direction. If, however, we assume that the downstream dispersion is comparable with cross-stream diffusion this effect leads to at most a 15% underestimate at dilutions of the order of 30,000:1.

5) Scaling with Pumping Rate

A large unknown factor in our experimental work is the way in which measured quantities depend upon pumping rate. Again, we take two different points of view which represent the extremes. From the diffusion point of view, increasing the pumping rate will simply lead to a corresponding increase in the concentration at every point. The stream line flow point of view, however, would be scaled by an area R/U. This area is the area through which the contaminate flows. From this point of view, then, it is reasonable to assume that the cross-stream width of the plume is increased when the pumping rate is increased.

We have plotted dilution contours which show each of these assumptions for a tripling of the pumping rate at the Pompano Lift Station. A factor of three was chosen because that would represent saturation capacity of the pumping capability of the present lift station.

6) Dilution Contours

Sewage outfall plumes were reconstructed from the fluorometry experiments using the before mentioned techniques to plot the dilution contours shown in Figures 134-149. These plots represent equal contour lines of 1000 T.C./100 ml based on:

1. The observed Gaussian fit data using:
    a. no die-off
    b. winter die-off
    c. summer die-off
2. Three times the concentration.
    a. no die-off
3. Three times the standard deviation.
    a. no die-off

Therefore, the area inside a set of dilution contours has a bacteria concentration in excess of the state standard 1000 T.C./100 ml, and the bacteria concentration outside of the contour is below the standard. The length of the contours from the outfall is a function of the rate at which dye is being pumped into the outfall, the amount of time since the dye was started and the current speed. These factors are important as to the amount of dilution the dye will undergo. Field measurements normally lasted about 4 hours, at which time the dye concentration was diluted to the point where it was no longer measurable with the fluorometer. Bacteria samples were taken by personnel from the Palm Beach County Health Department at the peak dye concentration along a traverse. These samples were iced, and transported back to the shore laboratory for determination of numbers, using standard tube, dilution techniques.

This method was found not to be satisfactory due to the long and variable time spans between collection and analysis. However, the concentration of Total Coliforms/100 ml as measured in this manner at the last traverse of an experiment is shown in brackets. In general the bracketed values of bacteria are in agreement with the dilution contours.

The dilution contours of the observed data with no die-off and winter die-off show a large area of surface water with

FIGURES 134-149

Dilution Contours of 1000 T.C./100 ml

1. Gaussian Fit
   Observed:

   No Die-off ________
   Winter Die-off --------
   Summer Die-off ....

   3 x Initial Concentration:

   No Die-off -.-.-.-.

   3 x Standard Deviation:

   No Die-off --..--..

2. Sample Fit
   Observed:

   No Die-off -o-o-o-o

   Current Speed (knots) ⟶

   Wind Speed (knots) ⟹

3. Measured Bacteria Concentration

   Total Coliforms/100 ml - [ ]

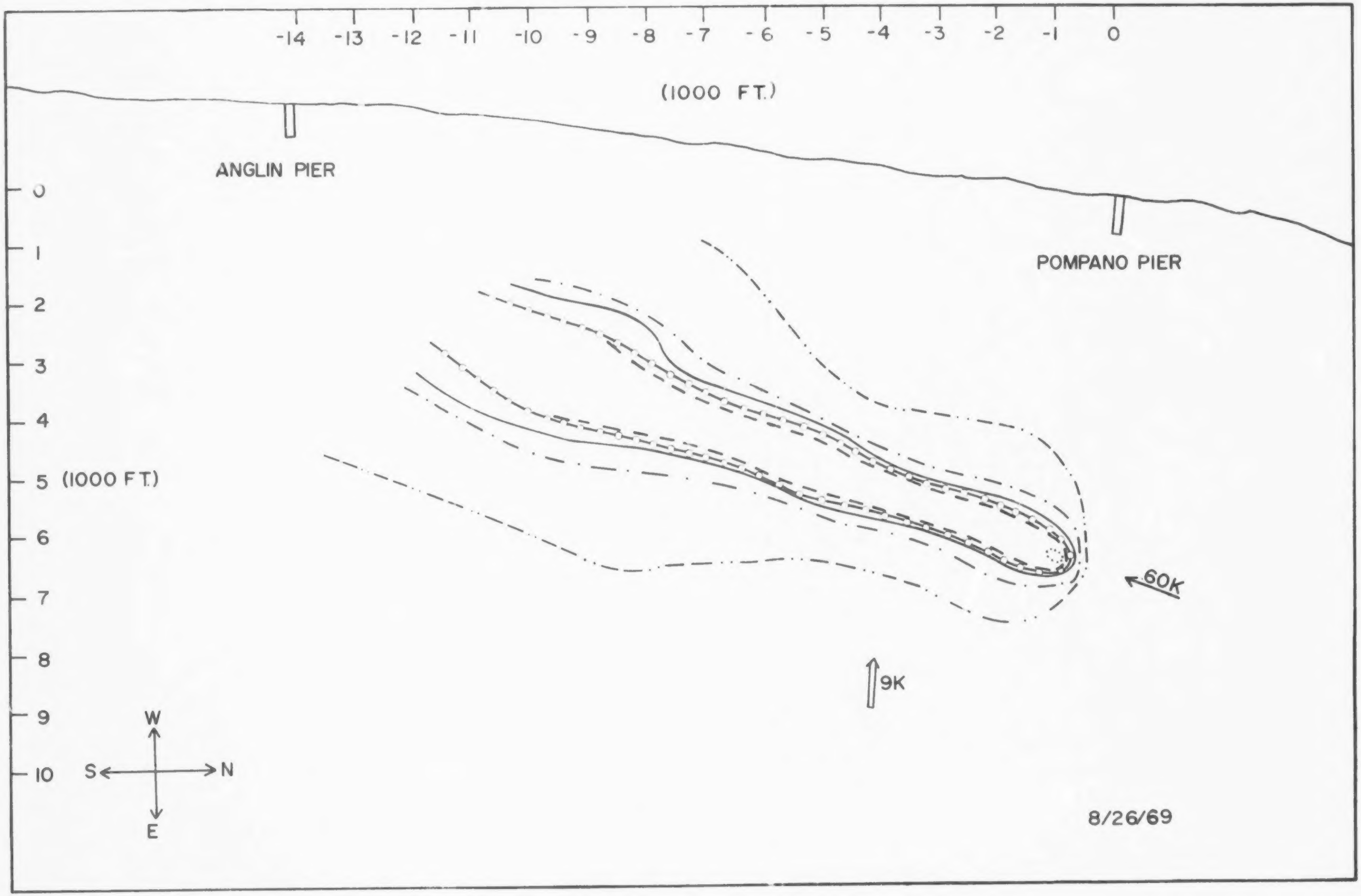

-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
(1000 FT.)
ANGLIN PIER
POMPANO PIER
0
1
2
3
4
5
6
7
8
9
10
(1000 FT.)
60K
9K
W
S
N
E
8/26/69

Fig. 134

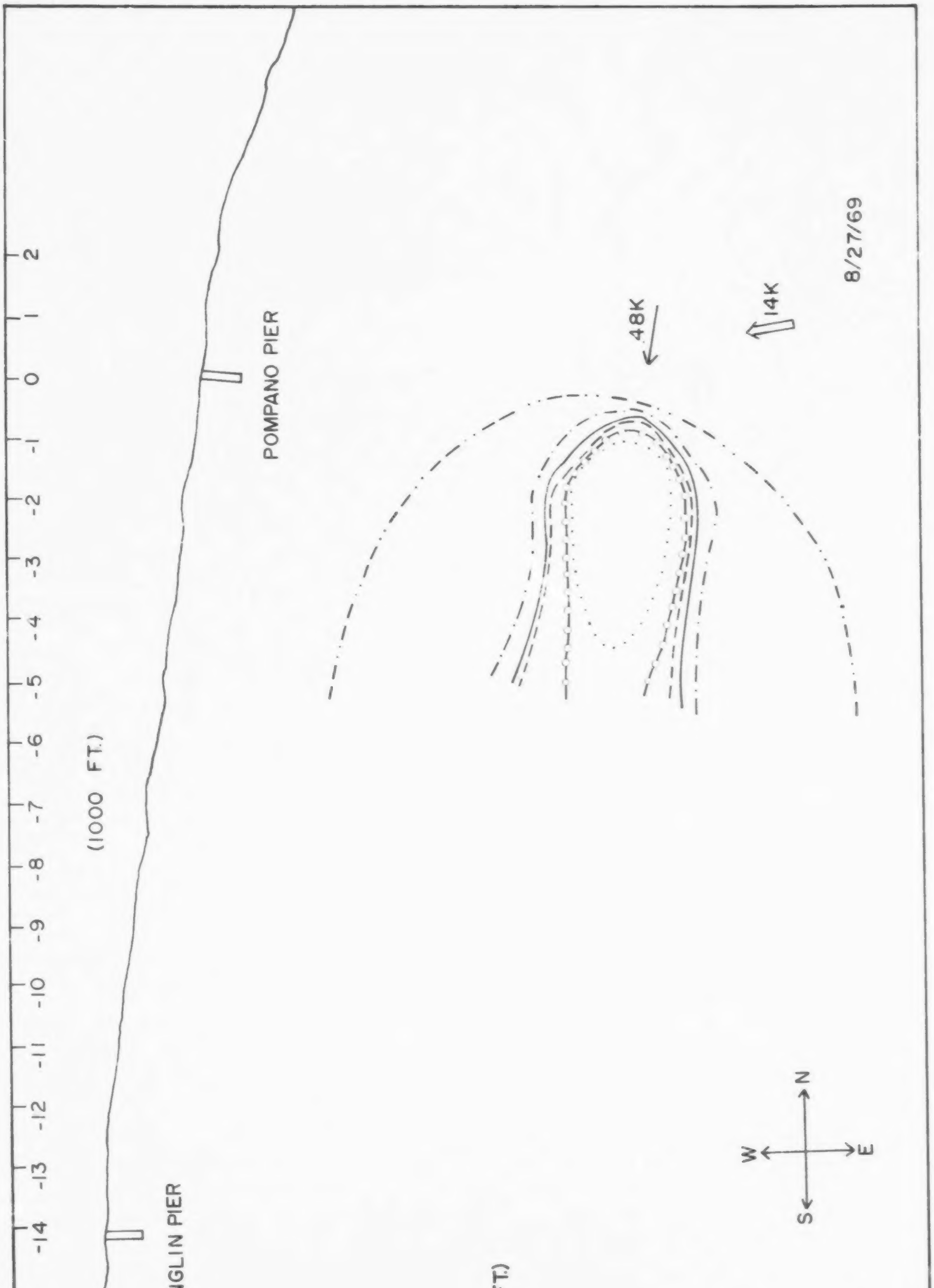

POMPANO PIER
ANGLIN PIER
(1000 FT.)
5 (1000 FT.)
48K
14K
8/27/69
N
S
E
W
-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
0
1
2
3
4
6
7
8
9
10

Fig. 135

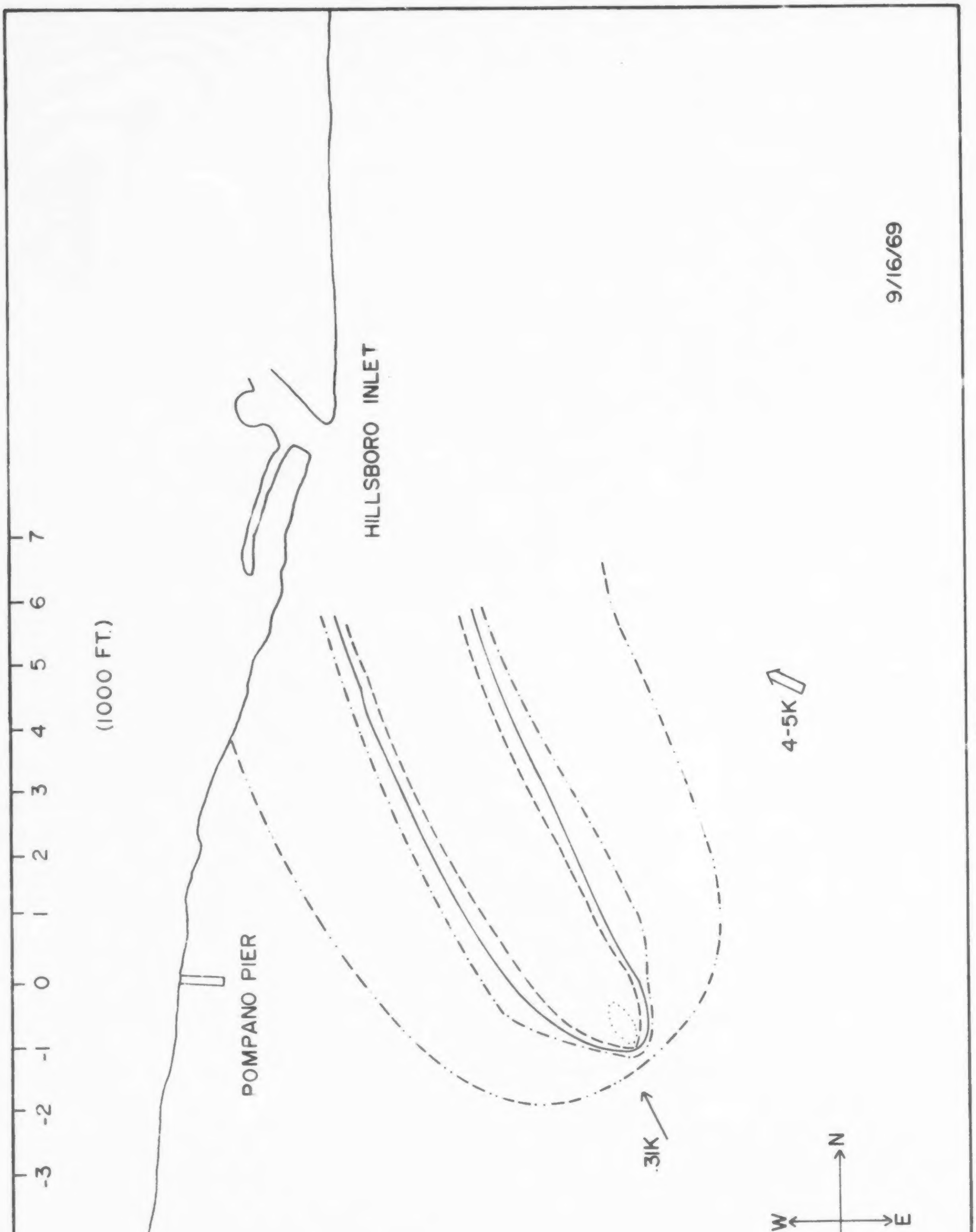

(1000 FT.)
-3
-2
-1
0
1
2
3
4
5
6
7
(1000FT.)
0
1
2
3
4
5
6
7
8
POMPANO PIER
HILLSBORO INLET
.31K
4-5K
W
N
S
E
9/16/69

Fig. 136

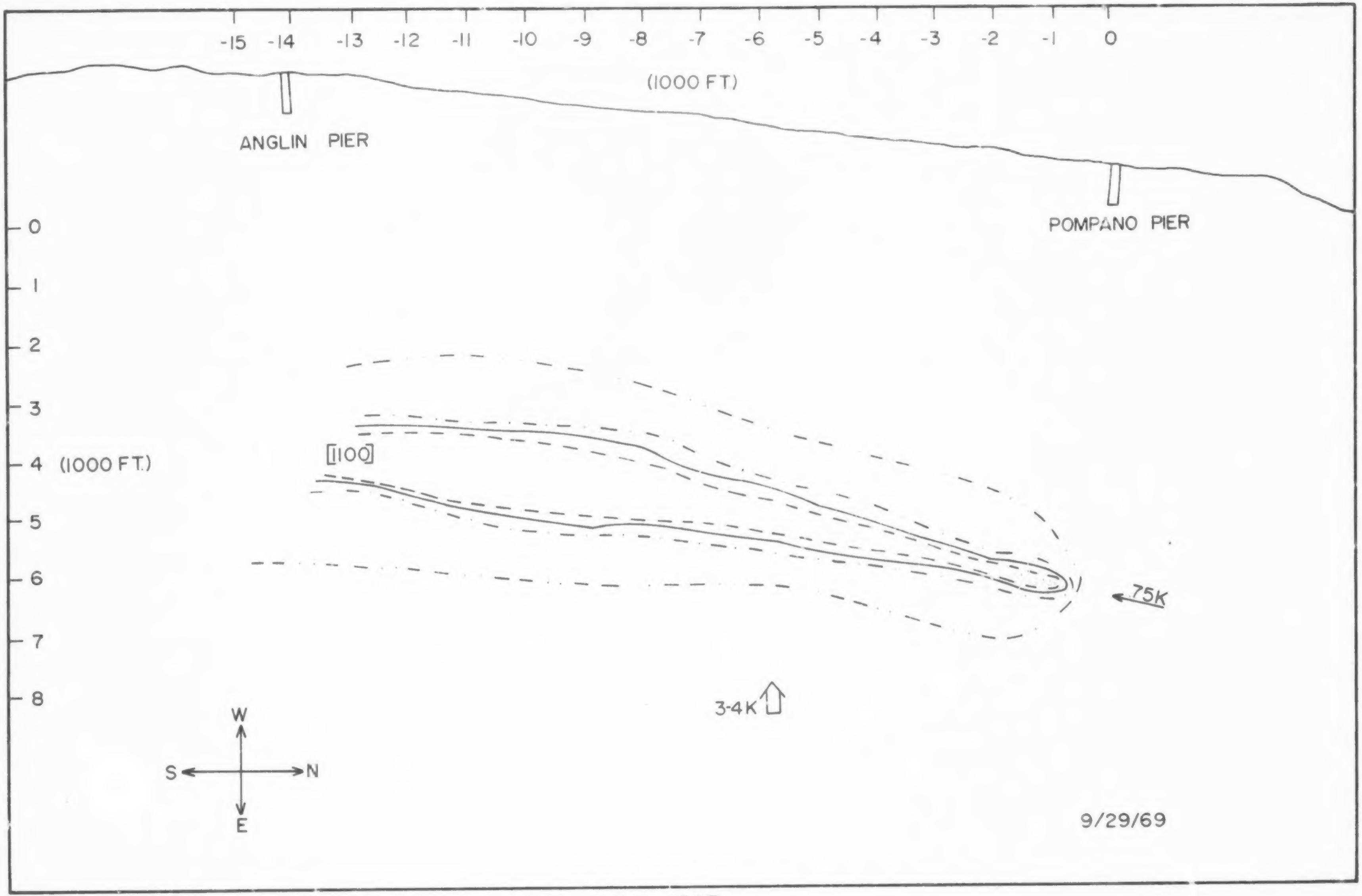

-15
-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
(1000 FT)
ANGLIN PIER
POMPANO PIER
0
1
2
3
4
5
6
7
8
(1000 FT.)
[100]
75K
3-4K
W
S
N
E
9/29/69

Fig. 137

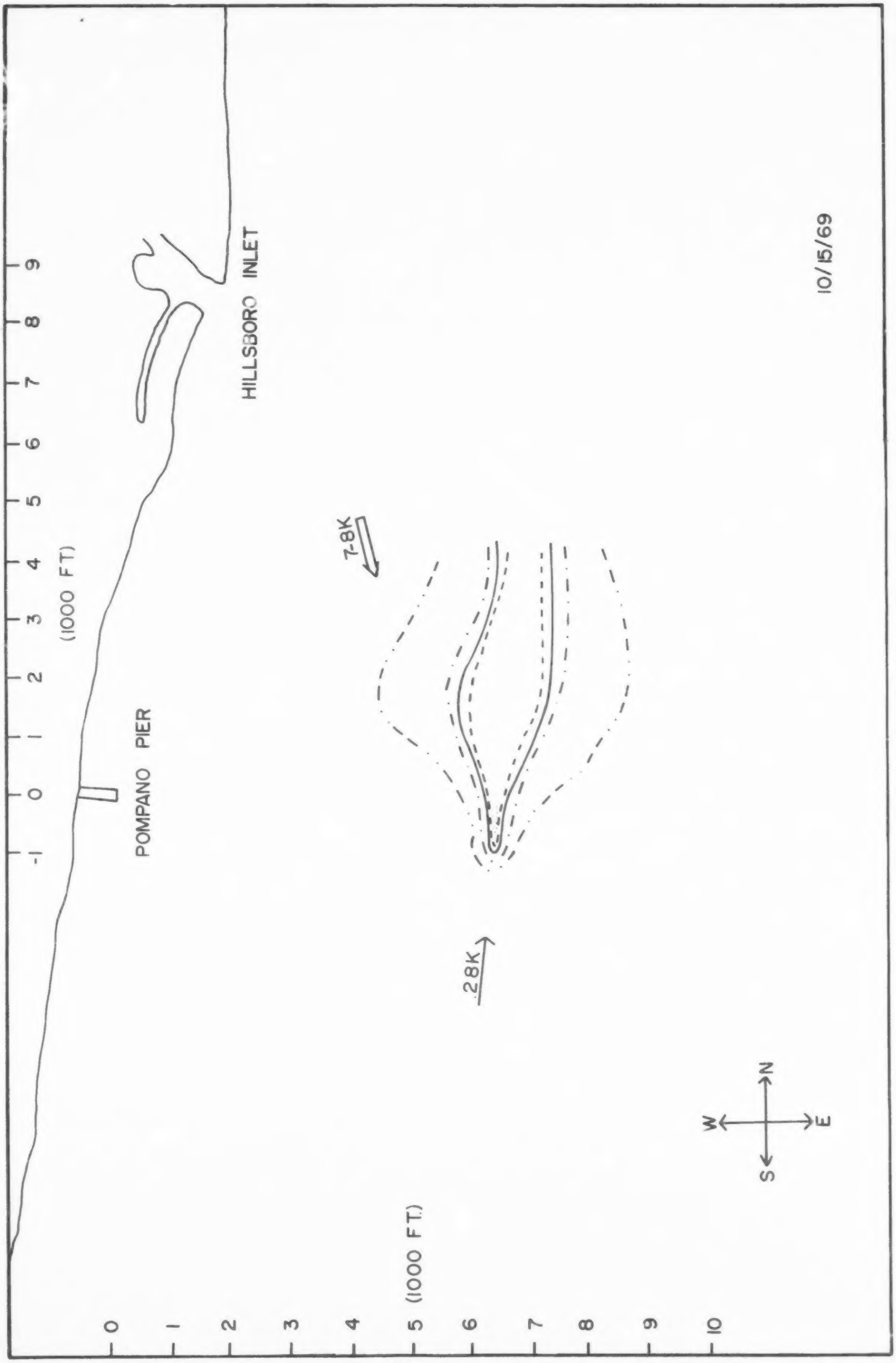

HILLSBORO INLET
POMPANO PIER
(1000 FT)
(1000 FT.)
-1
0
1
2
3
4
5
6
7
8
9
10
7-8K
.28K
N
S
E
W
10/15/69

Fig. 138

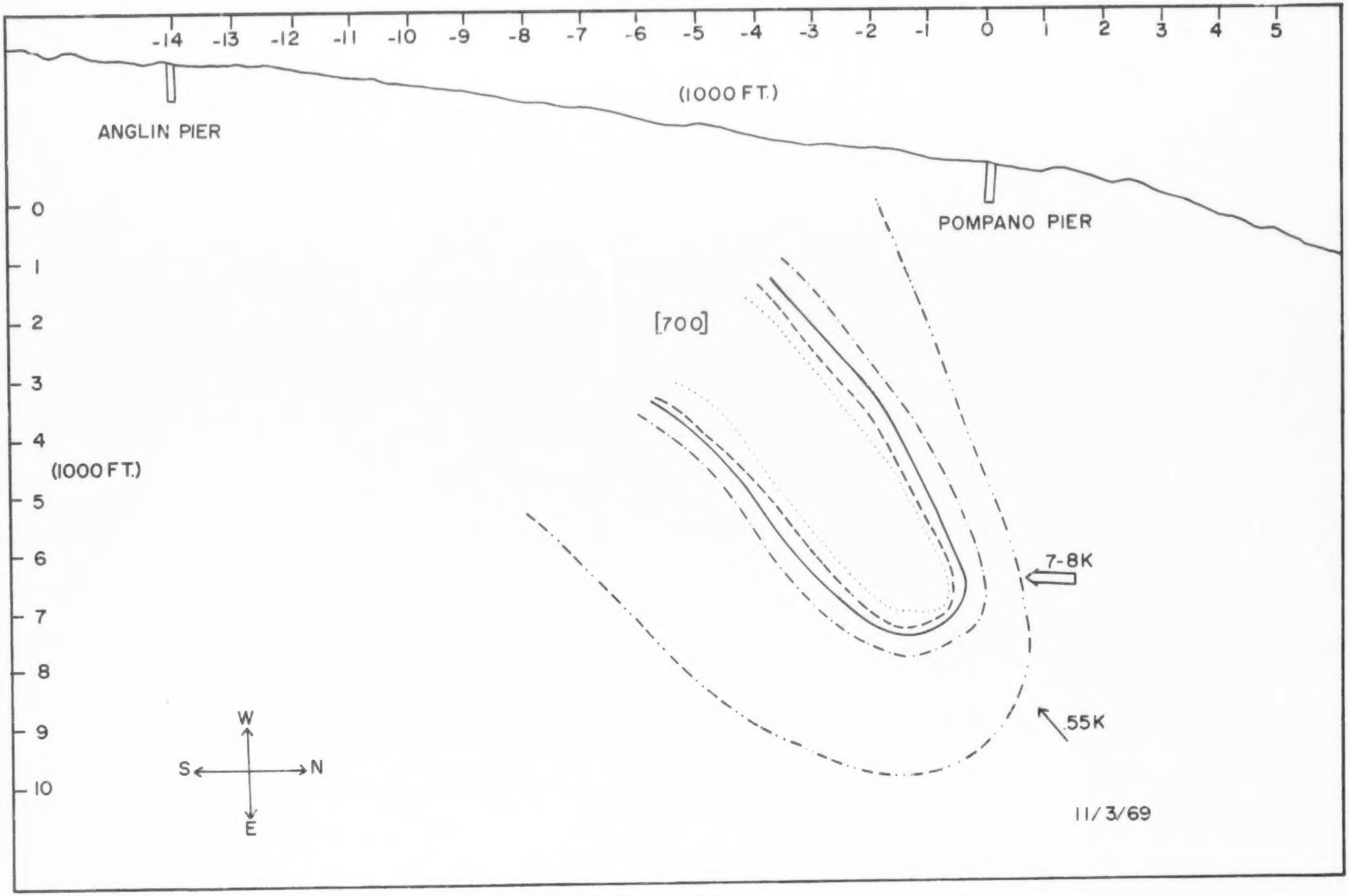

-14
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
(1000 FT.)
ANGLIN PIER
POMPANO PIER
0
1
2
3
4
5
6
7
8
9
10
(1000 FT.)
[700]
7-8K
.55K
W
S
N
E
11/3/69

Fig. 139

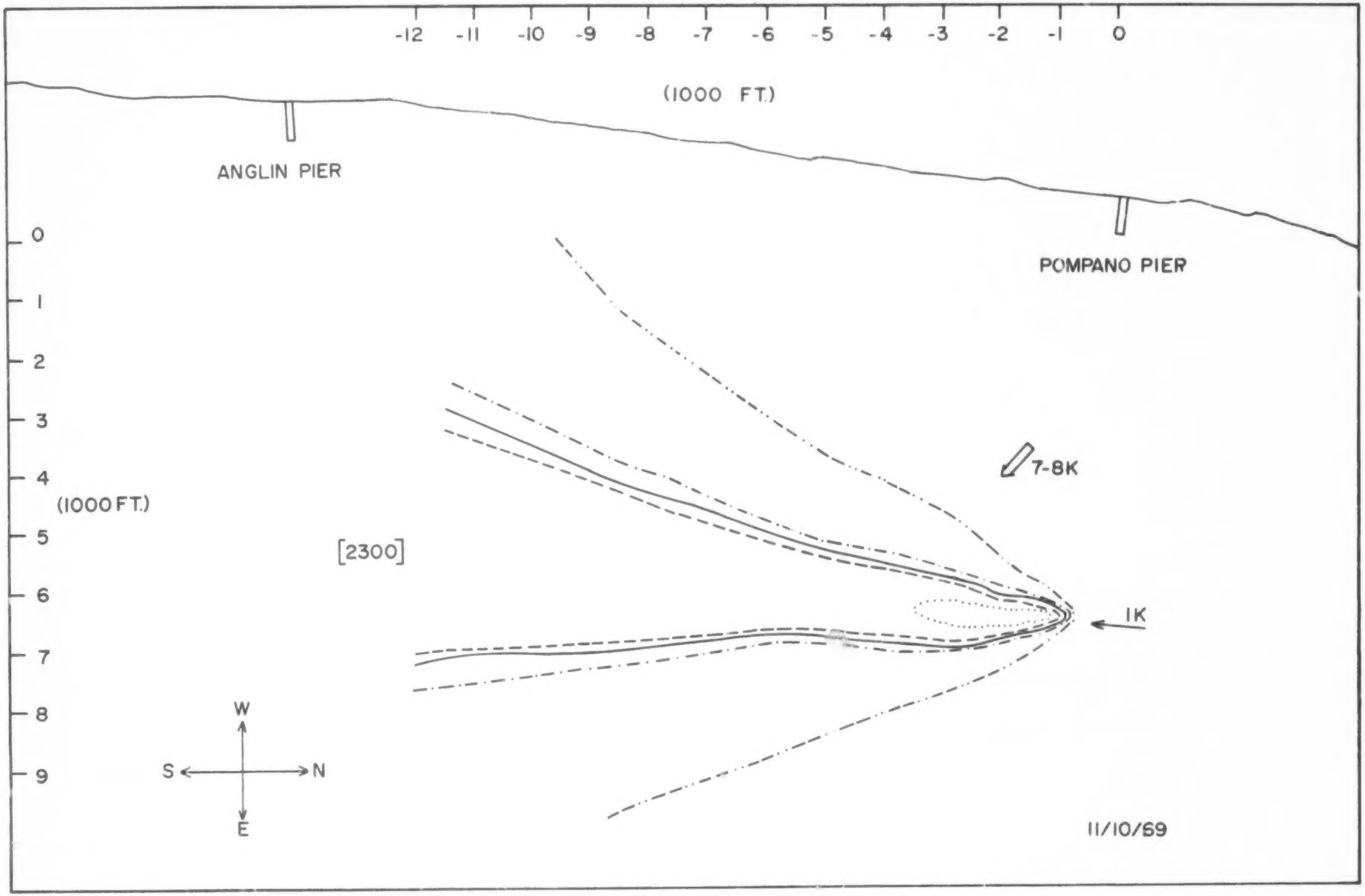

-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
(1000 FT.)
ANGLIN PIER
POMPANO PIER
0
1
2
3
4
5
6
7
8
9
(1000 FT.)
[2300]
7-8K
1K
W
S
N
E
11/10/69

Fig. 140

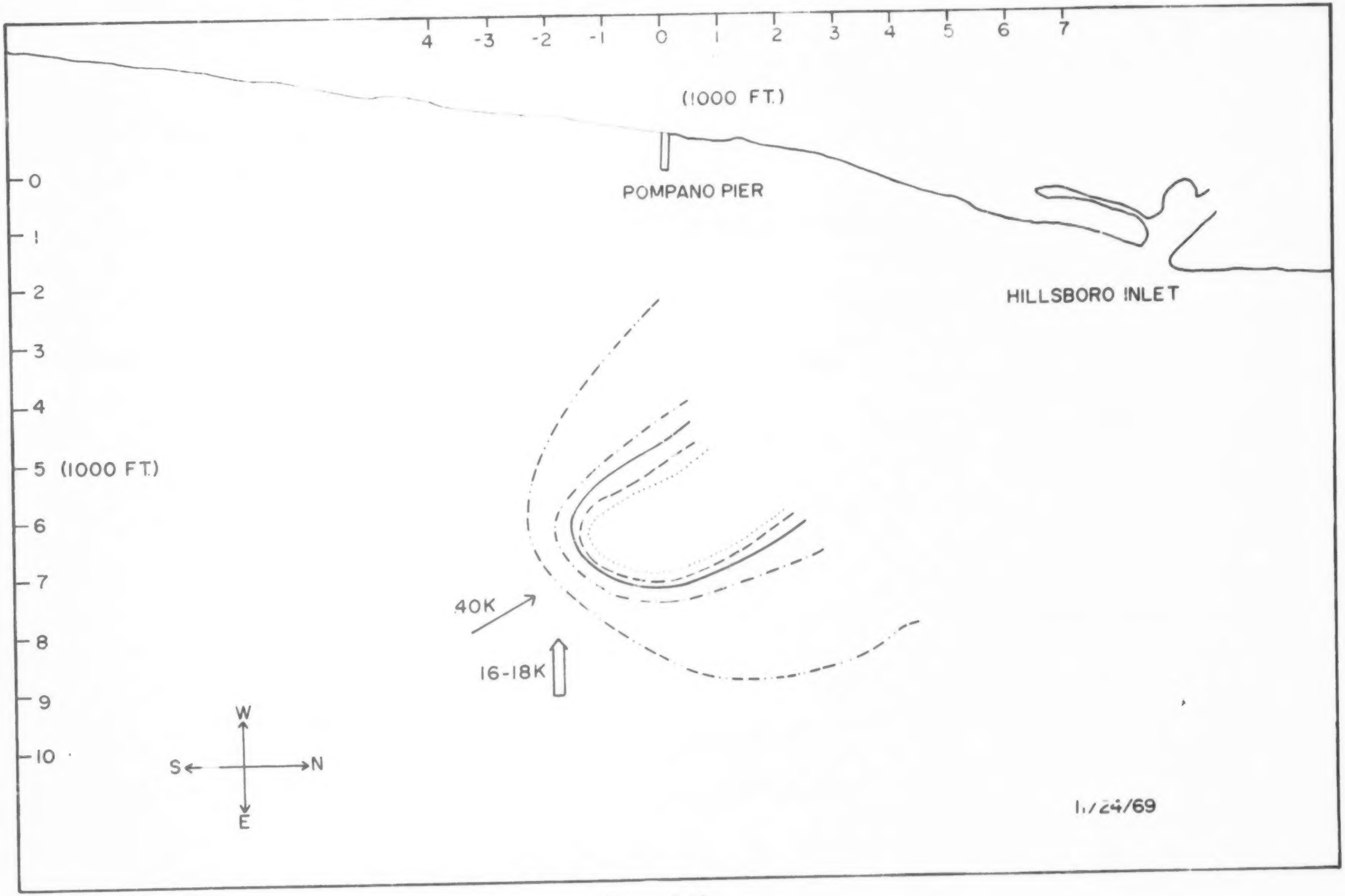

4
-3
-2
-1
0
1
2
3
4
5
6
7
(1000 FT.)
POMPANO PIER
HILLSBORO INLET
0
1
2
3
4
5 (1000 FT.)
6
7
8
9
10
40K
16-18K
W
S
N
E
1/24/69

Fig. 141

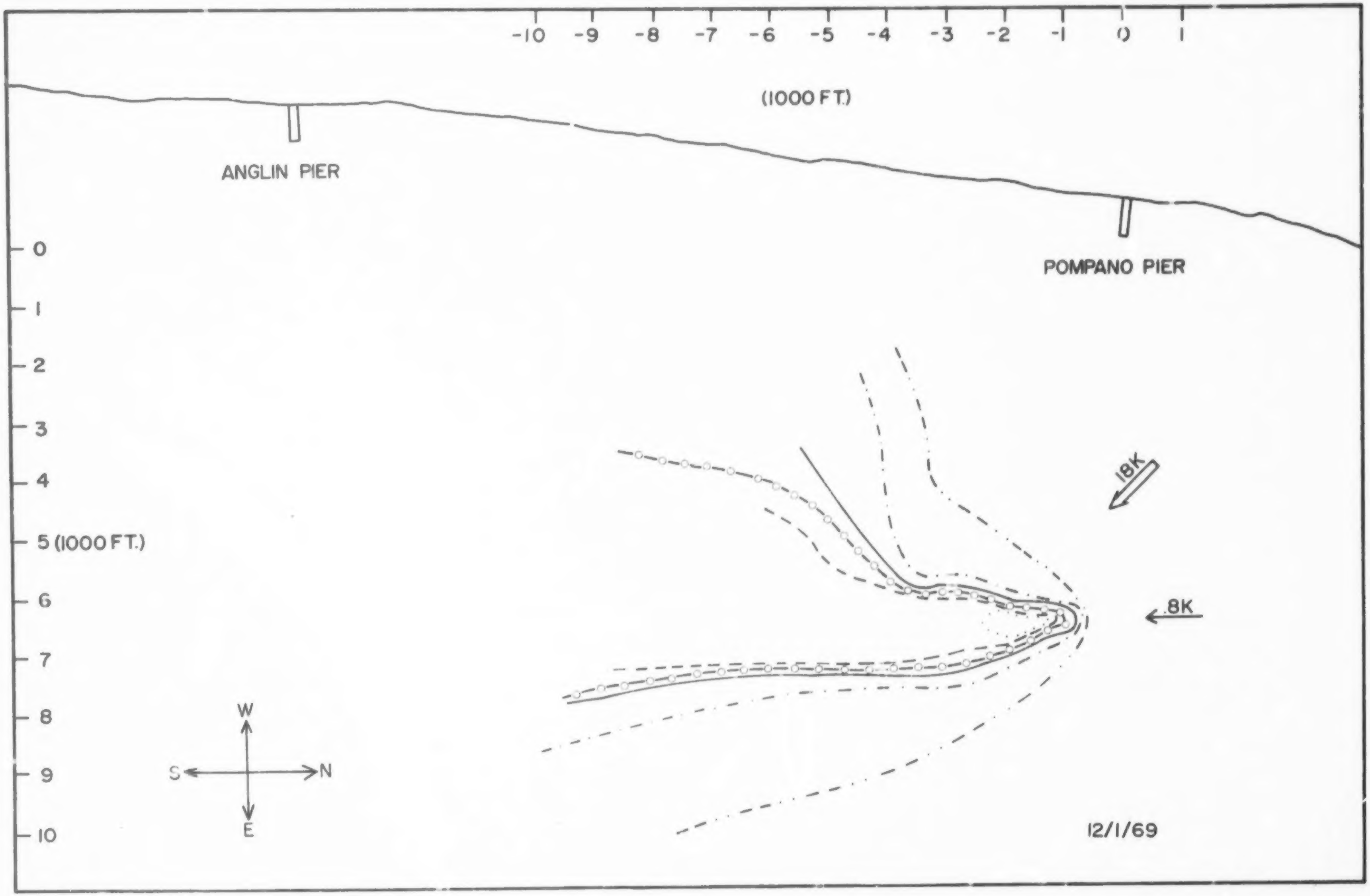

-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
(1000 FT.)
ANGLIN PIER
POMPANO PIER
0
1
2
3
4
5 (1000 FT.)
6
7
8
9
10
18K
.8K
W
S
N
E
12/1/69

Fig. 142

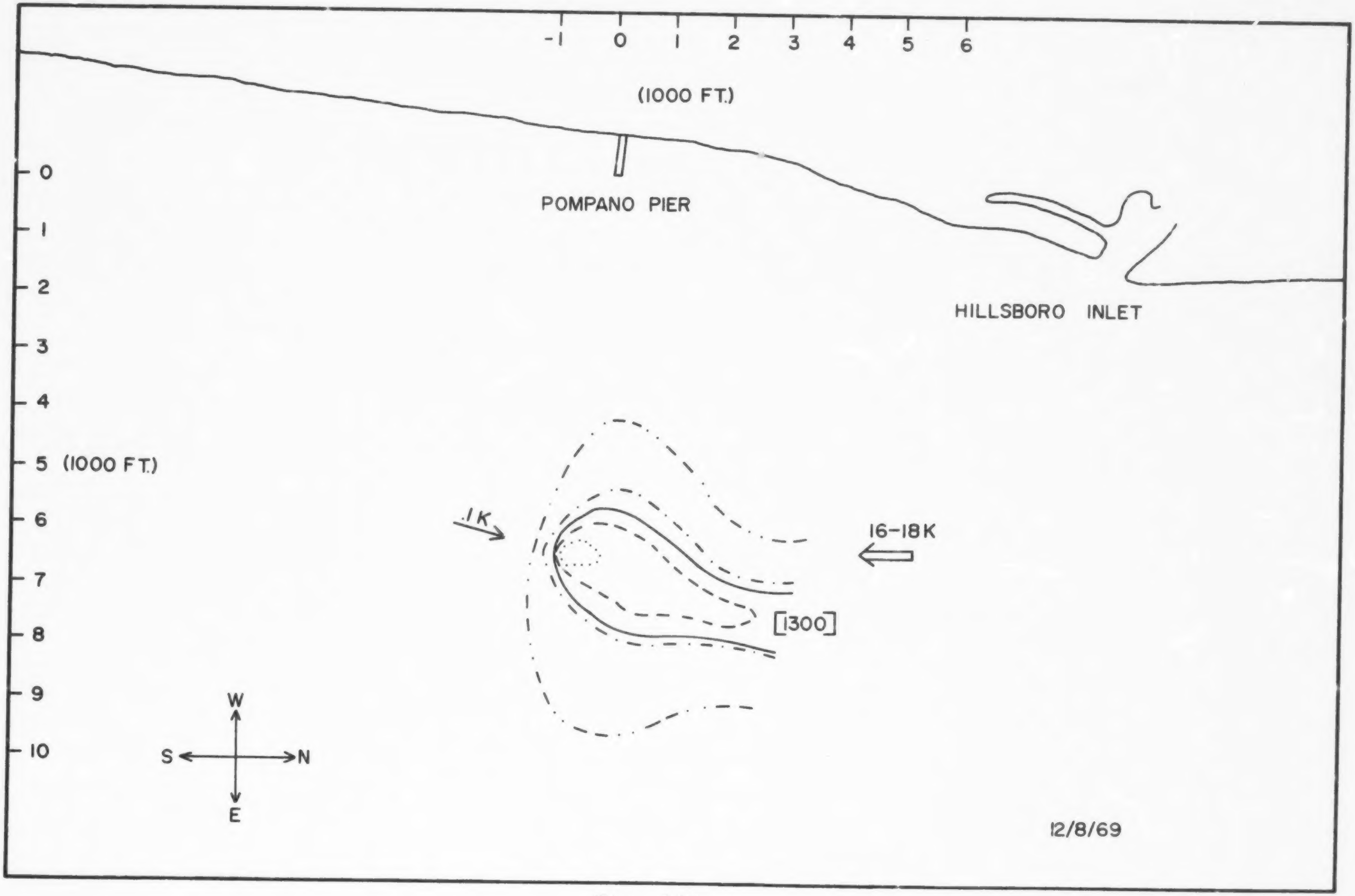

-1
0
1
2
3
4
5
6
(1000 FT.)
POMPANO PIER
HILLSBORO INLET
0
1
2
3
4
5 (1000 FT.)
6
7
8
9
10
.1K
16-18K
[1300]
W
S
N
E
12/8/69

Fig. 143

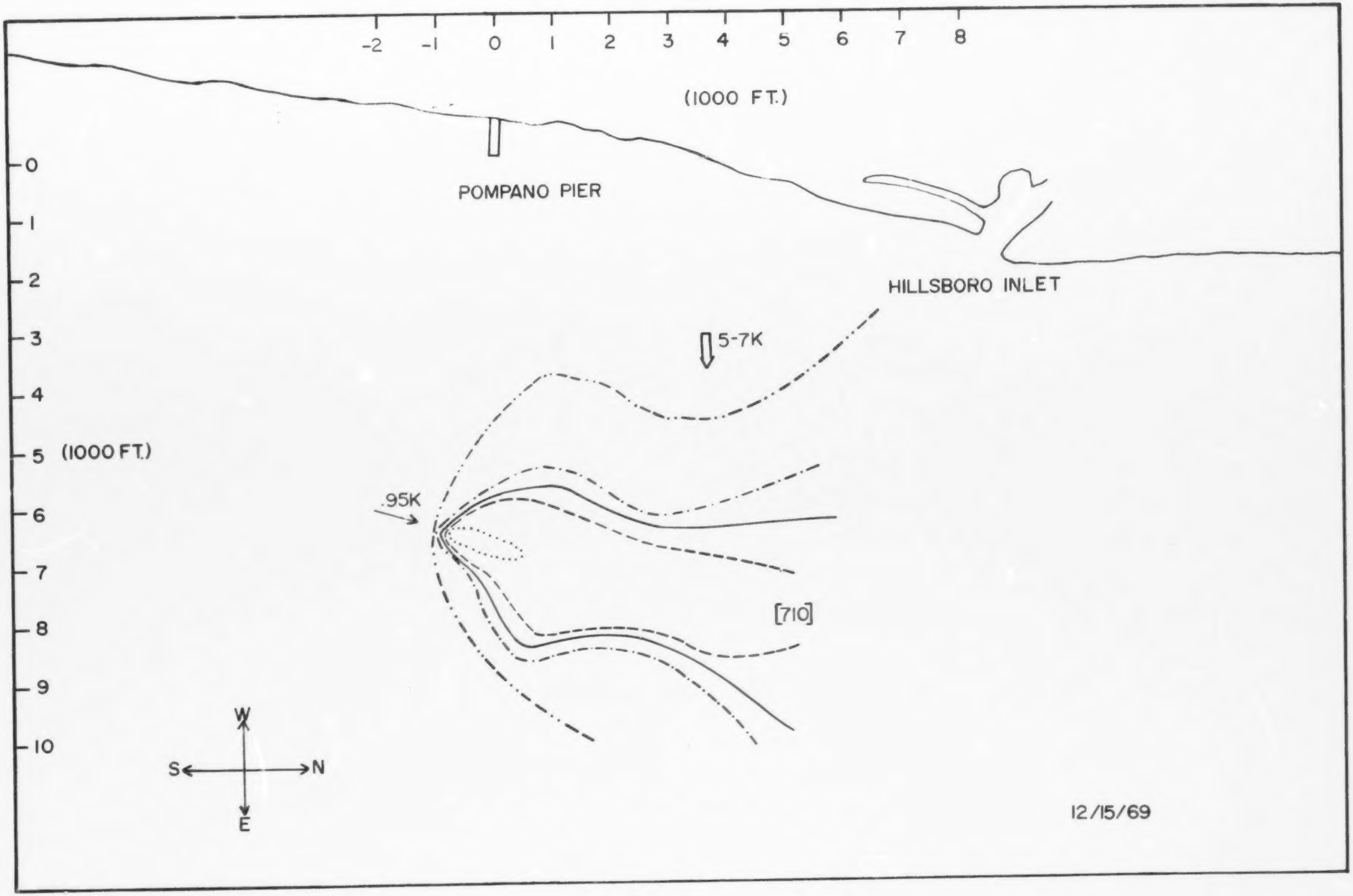

-2
-1
0
1
2
3
4
5
6
7
8
(1000 FT.)
POMPANO PIER
HILLSBORO INLET
0
1
2
3
4
5
6
7
8
9
10
(1000 FT.)
5-7K
.95K
[710]
W
S
N
E
12/15/69

Fig. 144

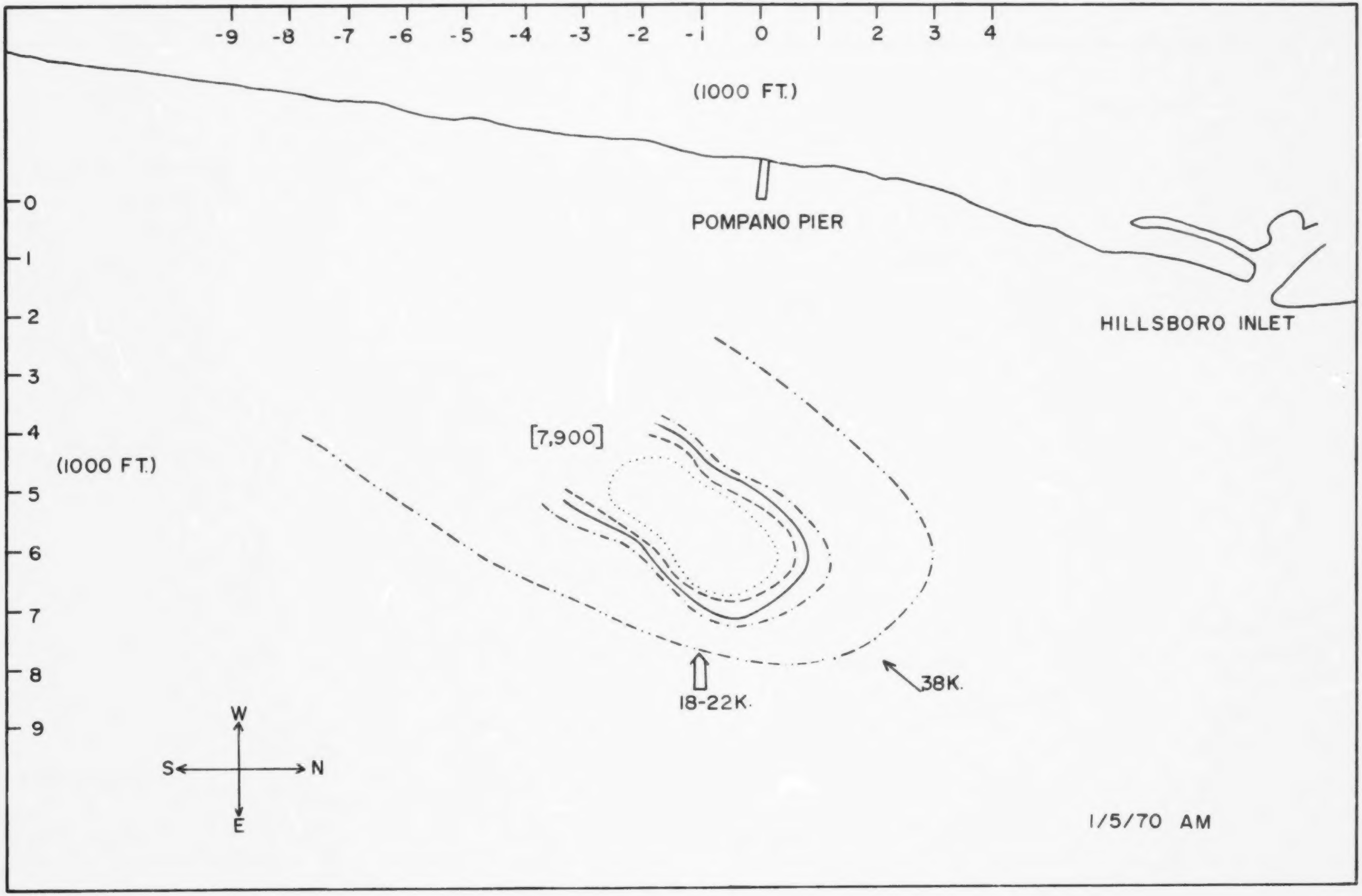

-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
(1000 FT.)
0
1
2
3
4
5
6
7
8
9
(1000 FT.)
POMPANO PIER
HILLSBORO INLET
[7,900]
18-22K.
38K.
W
S
N
E
1/5/70 AM

Fig. 145

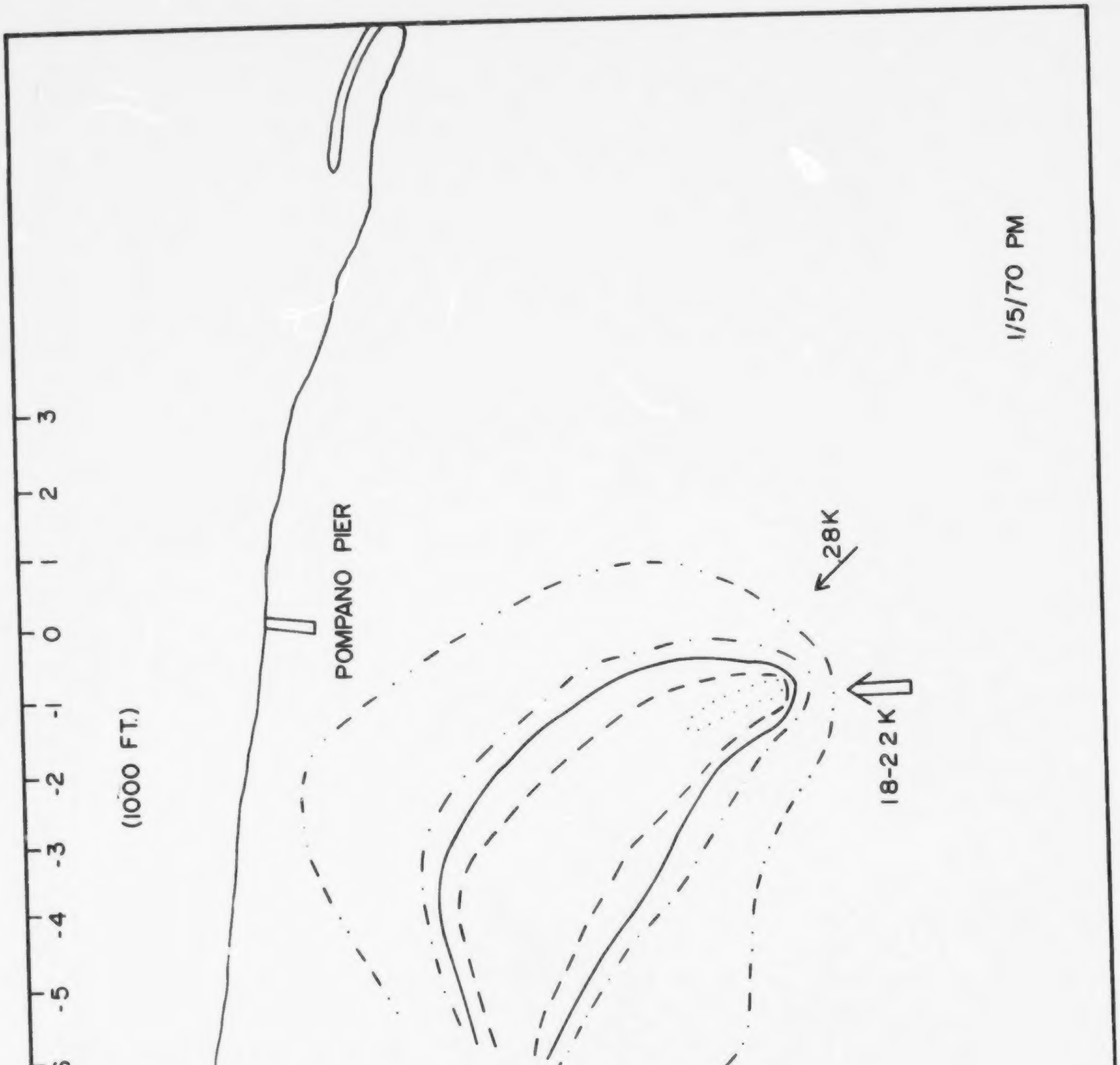

ANGLIN PIER
POMPANO PIER
(1000 FT.)
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
(1000 FT.)
0
1
2
3
4
5
6
7
8
28K
18-22 K
1/5/70 PM
N
S
E
W

Fig. 146

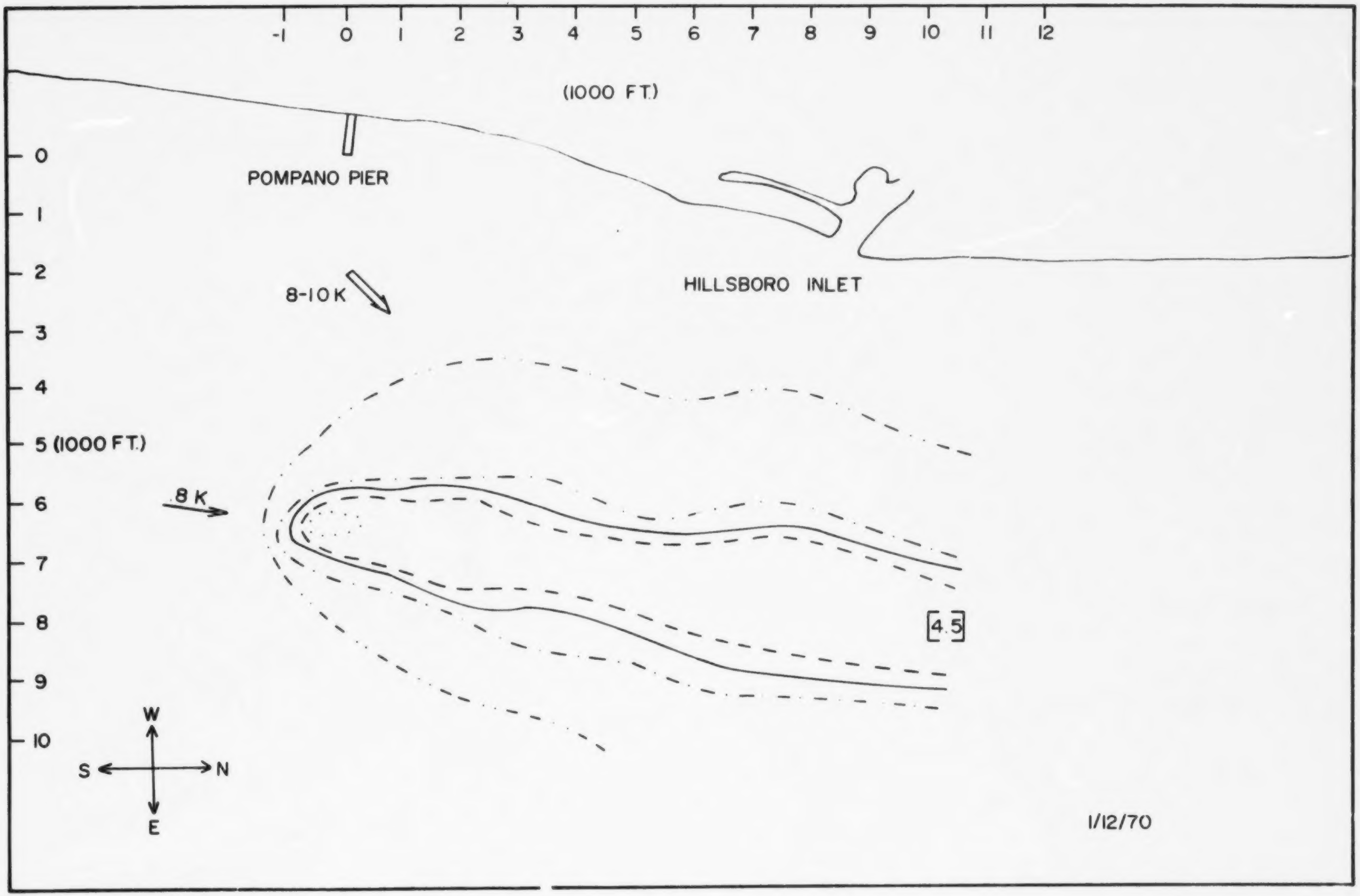

-1
0
1
2
3
4
5
6
7
8
9
10
11
12
(1000 FT.)
POMPANO PIER
HILLSBORO INLET
8-10K
0
1
2
3
4
5 (1000 FT.)
6
7
8
9
10
8 K
4.5
W
S
N
E
1/12/70

Fig. 147

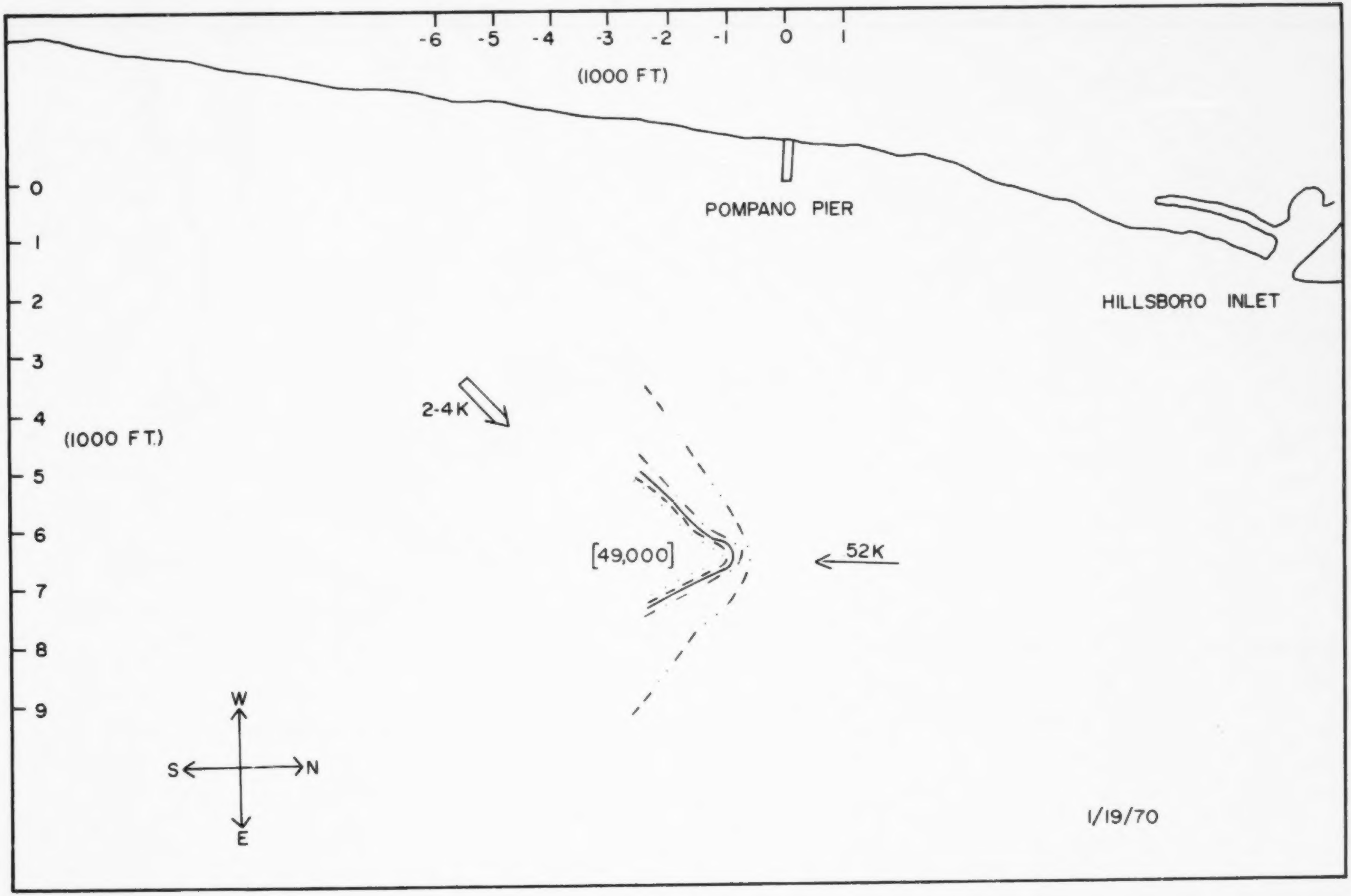
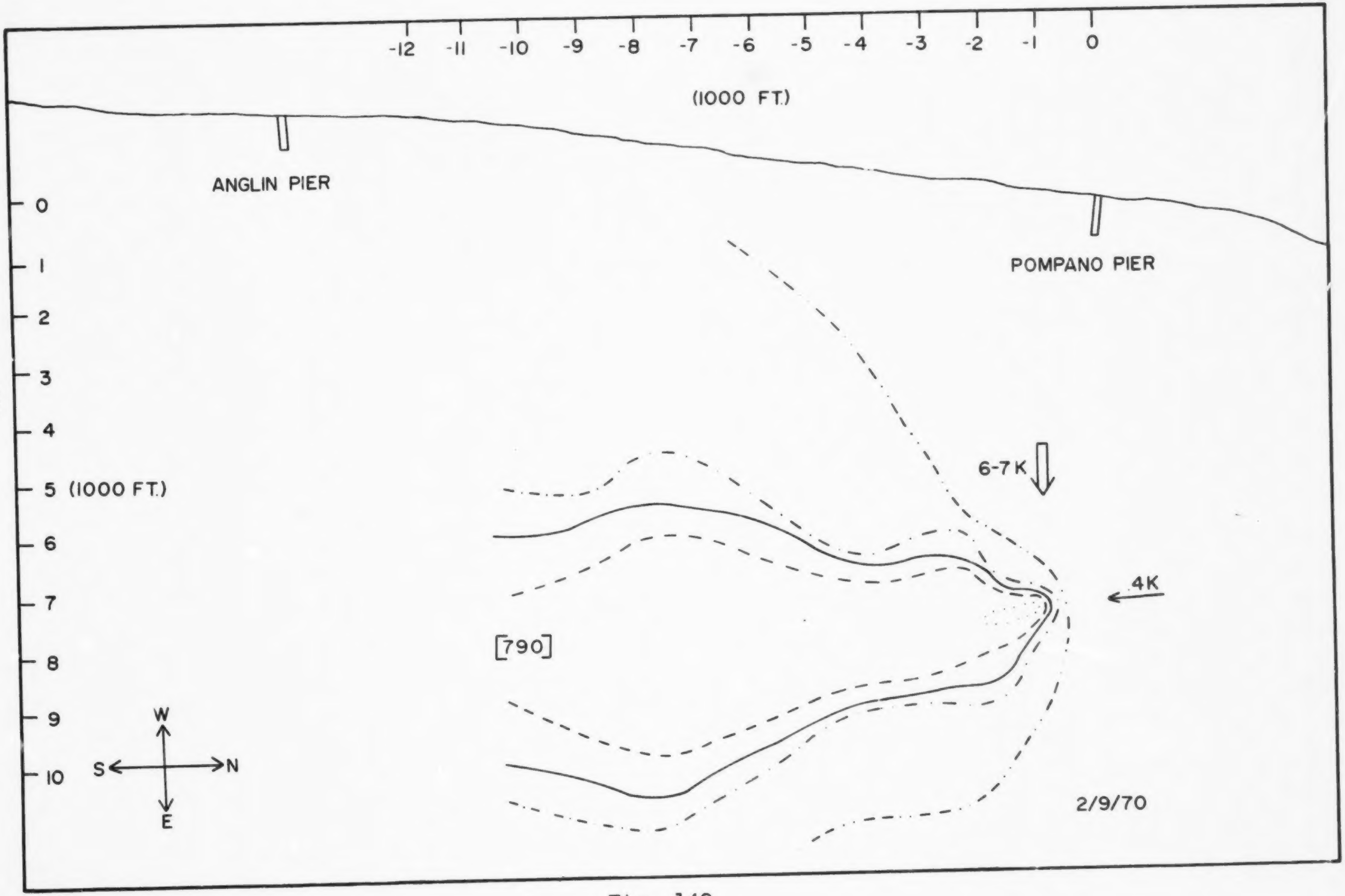

-6
-5
-4
-3
-2
-1
0
1
(1000 FT)
POMPANO PIER
HILLSBORO INLET
0
1
2
3
4
5
6
7
8
9
(1000 FT.)
2-4K
[49,000]
52K
W
S
N
E
1/19/70

Fig. 148



-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
(1000 FT.)
ANGLIN PIER
POMPANO PIER
0
1
2
3
4
5 (1000 FT.)
6
7
8
9
10
6-7 K
4K
[790]
W
S
N
E
2/9/70

Fig. 149

bacteria counts in excess of the standard for bathing waters, stretching out several miles from the outfall. Winter die-off contours show very little difference from the no die-off contour. The only winter die-off contour that closes is in Figure 143. The low current speed of 0.1 knot on this experiment enabled a travel time of around 5 hours to close the contour. The summer die-off contours close a short distance from the outfall, restricting the polluted region to a small area around the outfall in most cases. However, for the experiments shown in Figures 139 and 141 the summer die-off contours do not close.

The effect of tripling the pumping rate of the Pompano outfall is shown in the dilution contours by either increasing the concentration threefold or by tripling the cross stream standard deviation. This represents the result of using either a diffusion model or a streamline model, respectively. Since both processes are taking place the end result of tripling the pumping rate will probably lie somewhere between the two views. Increasing the concentration will cause the contours to extend further downstream. Increasing the cross stream standard deviation will extend the width of the contours. Both view points will greatly increase the area of polluted water within the contours. Figures 134, 135, and 142 also show the dilution contour for the observed data with no die-off using the sample fit analysis. These curves are in good agreement with the similar curves of the Gaussian fit contours. The width of the plumes are slightly smaller using the sample fit techniques as was previously suggested would occur.

In general the effluent plumes as shown by the dilution contours stretch out to the north or south and show a shoreward component in direction, which is dependent on the strength of the onshore wind. The likelihood of an effluent plume reaching the bathing waters with bacteria counts higher than the standard increases as the intensity of onshore winds increase. Figures 134, 136, 139, 141, 142, and 145 show experiments where it is apparent that if the plume continues in the direction indicated then water with bacteria counts in excess of 1000 T.C./100 ml will reach the public bathing waters.

It is evident from the dilution contours that outfall effluent plumes need to be tagged and traced for longer time periods. If dye is used as the tracer this means pumping dye at a much greater rate and for longer periods, which is a large monetary expense.

SANITARY ENGINEERING APPLICATIONS

Sewage effluent discharged from the Pompano outfall has a salinity near that of fresh water (1.0 0/00) at the point of discharge. The salinity of the receiving shelf water is approximately 35 0/00. Thus, the effluent being less dense than the shelf water will rise to the surface, forming a "boil". The diffusion and mixing of the rising effluent is very vigorous. Salinity of the effluent within the boil is only 1 to 2 0/00 less than the shelf water. Initial dilutions on the order of 100:1 to 200:1 are quite common. If the shelf water at the point of discharge is stably stratified and strong currents are present then the rising of the effluent will be hindered. If these conditions are strong enough, the effluent will be prevented from rising to the surface and mixed at some subsurface depth. The stability of the water column can be thought of as the vertical gradient in sigma-t (σ_t) or density. The vertical gradient of sigma-t $\Delta\sigma_t/\Delta z$ calculated from the surface to a depth of 90 feet (outfall depth) is plotted against surface current speed in Figure 150 as a log-log plot. Stability was calculated from measured values of temperature and salinity at 90 feet and the surface. Surface currents were measured with free drifting current crosses. The formation of an effluent surface "boil" was noted on each experiment. Figure 150 indicates that there is a critical relationship between current speed and stability beyond which a boil will not form. A solid line was drawn through the data points to represent this critical relation for boil formation. The regression coefficients were determined from the data points associated with this line. The critical relationship for boil formation was then determined as:

$$v = 0.36(\Delta\sigma_t/\Delta z)^{-1.7} \qquad (22)$$

Thus, if the current speed and stability combination lies above this line the effluent will be mixed at some subsurface level and greatly reduce the probability of it reaching the bathing waters. This relationship needs much more data to give it validity, especially in the late spring and early summer when strong stratification predominates.

Effluent being discharged from the Pompano outfall will undergo an initial dilution on rising to the surface and a downstream dilution in the plume due to mixing and dispersion with the shelf water. The sum of these two dilutions is the total dilution the effluent will undergo at some point downstream after discharge. The total dilution from the initial concentration in the lift station to the peak concentration on a traverse was determined for every fluorometry experiment. A composite log-log plot of the total dilution (Gaussian fit) at each transect against the x distance downstream to the transect is shown in Figure 151 for the data from all experiments. The "ones" symbolize actual data points. A second degree polynomial was fitted through the data points using least square fitting and is plotted as "twos". If we let:

x = Downstream Distance

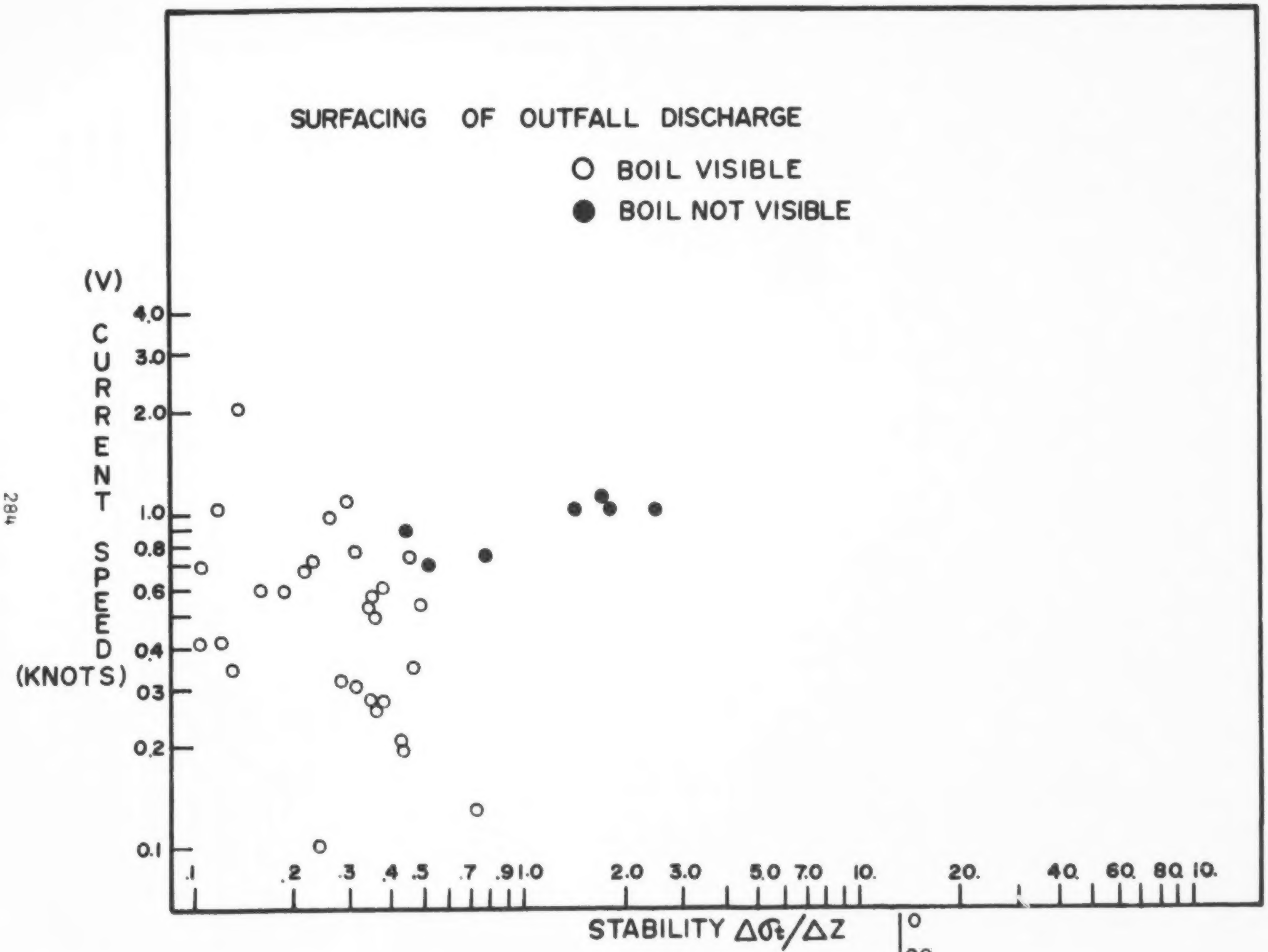

SURFACING OF OUTFALL DISCHARGE
○ BOIL VISIBLE
● BOIL NOT VISIBLE
(V) CURRENT SPEED (KNOTS)
4.0
3.0
2.0
1.0
0.8
0.6
0.4
03
0.2
0.1
.1
.2
.3
.4
.5
.7
.9
1.0
2.0
3.0
5.0
7.0
10.
20.
40.
60.
80.
10.
STABILITY $\Delta\sigma_t/\Delta Z$ $|^{0}_{90}$

Fig. 150

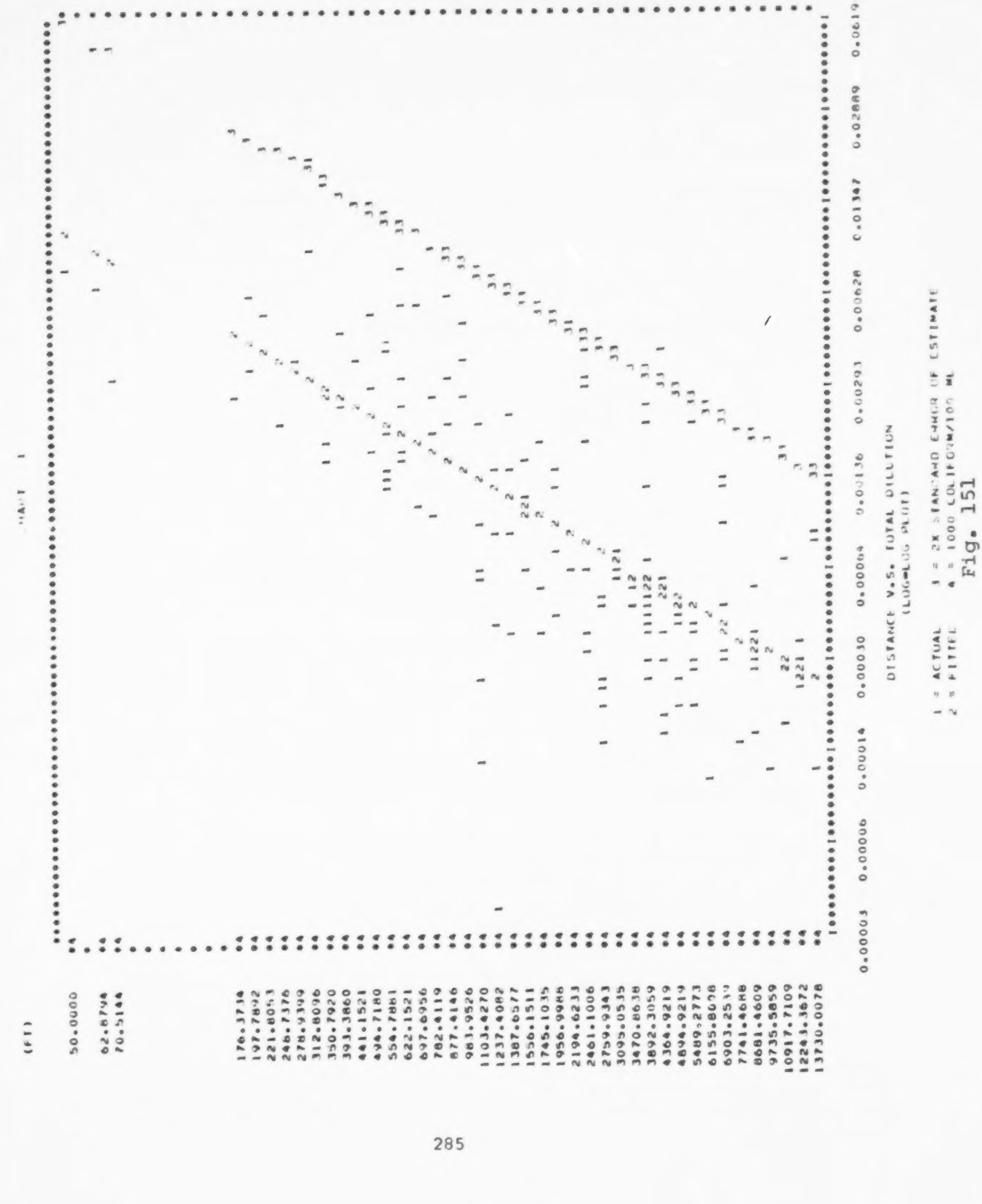

(FT)
50.0000
62.8794
70.5144
176.3734
197.7892
221.8053
248.7376
278.9399
312.8096
350.7920
393.3860
441.1521
494.7180
554.7881
622.1521
697.6956
782.4146
877.4146
983.9526
1103.4270
1237.4082
1387.6577
1556.1511
1745.1035
1956.9986
2194.6233
2461.1006
2759.9343
3095.0535
3470.8638
3892.3059
4364.9219
4894.9219
5489.2773
6155.8098
6903.2510
7741.4688
8681.4609
9735.5859
10917.7109
12243.3672
13730.0078
0.00003
0.00006
0.00014
0.00030
0.00064
0.00136
0.00291
0.00628
0.01347
0.02889
0.06197
DISTANCE V.S. TOTAL DILUTION
(LOG-LOG PLOT)
1 = ACTUAL
2 = FITTED
3 = 2X STANDARD ERROR OF ESTIMATE
4 = 1000 COLIFORM/100 ML

Fig. 151

y = Total Dilution
$X = \ln x$
$Y = \ln y$

then the regression function used to fit the data has the form:

$$Y = aX^2 + bX + c \tag{23}$$

The standard error of regression (e) was calculated and a function two times the standard error from Y was fitted to the data (plotted as threes) using

$$Y_e = aX^2 + bX + c + 2e \tag{24}$$

the coefficients were calculated to equal

$a = -0.002$
$b = -0.643$
$c = -1.965$
$e = 0.865$

therefore

$$Y_e = -0.002X^2 -0.643X -.235 \tag{25}$$

using equation 25, one is 97.7% confident that the total dilution will not be greater than Y_e, i.e., the data will lie to the left of the Y_e fit 97.7% of the time.

Assuming an initial concentration of 30×10^6 T.C./100 ml for raw sewage, a total dilution of 3.33×10^{-5} or less is necessary in order to reduce the initial concentration to 1000 T.C./100 ml. This total dilution is plotted as "fours" in Figure 151. Within a distance of 14,000 feet of the Pompano outfall, a total dilution of peak concentration in the plume has never been measured that would be sufficient to reduce the initial concentration to the state standard.

Equation (25) can be used to predict the total dilution at any point downstream from the boil with 97.7% confidence that the actual total dilution will not be a larger number than the predicted value. The total dilution was calculated at 500 foot intervals from the boil using equation (25). The results are presented in Table 24.

The outlet of the Pompano Outfall is located approximately 7400 feet offshore. At a distance of 7500 feet Table 24 shows a total dilution of 2.18×10^{-3}. This would reduce the initial concentration of 3×10^7 T.C./100 ml to 6.54×10^4 which is about 65 times greater than the standard. At 15000 feet from the outfall the total dilution of 1.36×10^{-3} will reduce the initial concentration to 4.08×10^4 which is 41 times larger than the standard for bathing waters.

TABLE 24

Total Dilution -vs- Distance: 97% confidence

Distance	Total Dilution	Distance	Total Dilution
500	1.35×10^{-2}	8000	2.08×10^{-3}
1000	8.47×10^{-3}	8500	2.00×10^{-3}
1500	6.45×10^{-3}	9000	1.92×10^{-3}
2000	5.31×10^{-3}	9500	1.85×10^{-3}
2500	4.57×10^{-3}	10000	1.79×10^{-3}
3000	4.04×10^{-3}	10500	1.73×10^{-3}
3500	3.64×10^{-3}	11000	1.68×10^{-3}
4000	3.33×10^{-3}	11500	1.63×10^{-3}
4500	3.07×10^{-3}	12000	1.58×10^{-3}
5000	2.86×10^{-3}	12500	1.54×10^{-3}
5500	2.68×10^{-3}	13000	1.50×10^{-3}
6000	2.53×10^{-3}	13500	1.46×10^{-3}
6500	2.40×10^{-3}	14000	1.42×10^{-3}
7000	2.28×10^{-3}	14500	1.39×10^{-3}
7500	2.18×10^{-3}	15000	1.36×10^{-3}

Using Millipore filtering techniques, bacteria die-off for Southeast Florida waters was determined by Putnam during the study by the city of Hollywood on the Hollywood outfall, Stewart (1969).

$$(MPN)_t = (MPN)_o\ e^{-.31t};\ \text{(winter)} \qquad (26)$$

water temperature 75°F

$$(MPN)_t = (MPN)_o\ e^{-1.55t};\ \text{(summer)} \qquad (27)$$

water temperature 85°F

where t = time (hours)

$(MPN)_t$ = most probable number of bacteria at time (t)

$(MPN)_o$ = most probable number of bacteria at time ($t = 0$)

Time (t) can be expressed using the current speed (v) and the distance downstream from the boil (d). The most frequent currents are to the north or south with a mean speed of 0.5 knots. Using the 0.5 knot current speed and the distance offshore of the Pompano outfall (7400 feet) equations (26) and (27) become:

$$(MPN)_t = (MPN)_o\ e^{-0.74} \qquad \text{(winter)}$$

$$(MPN)_t = (MPN)_o\ e^{-3.72} \qquad \text{(summer)}$$

This amounts to a reduction of the initial concentration at a distance of 7400 feet from the outfall of 4.77×10^{-1} and 2.42×10^{-2} for winter and summer die-off. The initial concentration will therefore undergo a total reduction due to dilution and die-off of 1.04×10^{-3} and 5.28×10^{-5}. This results in bacteria counts of 31,200 and 1,574 T.C./100 ml for the winter and summer at a distance of 7,400 feet from the outfall. At a distance of 15,000 feet the total reduction will yield bacteria counts of 14,100 and .31 T.C./100 ml for winter and summer. At approximately 30,000 feet downstream winter die-off will produce a total reduction of the initial concentration down to the bathing water standard.

Although the observed nearshore currents are produced mainly by the offshore Florida Current and are typically to the north or south there is an onshore component in the current direction. The current meter records, drift card experiments and dilution contours have shown that this onshore component can cause an outfall effluent plume to reach the bathing waters at some distance from the boil. Dilution of the effluent due to mixing and dispersion with shelf water and bacteria die-off have been shown to be insufficient in reducing the initial concentration of bacteria down to safe bathing water standards within a distance of 30,000 feet in the winter and 7,500 feet in the summer. It is therefore highly probable that during the winter season the combination of onshore winds, greater effluent pumping rate, weakly stratified water column and low bacteria die-off will cause bacteria concentrations greater than 1000 T.C./100 ml to occur in the bathing waters near the Pompano outfall.

In order to be 97% confident that polluted water from the Pompano outfall will not reach the bathing waters, the effluent should be treated to reduce bacteria counts to 1000 T.C./100 ml at a distance of 6000 feet from the outfall. Therefore, the closest to the shore that water with bacteria counts in excess of safe bathing standards would come is 1400 feet. This will restrict pollution in terms of bacteria counts to a plume stretching no more than 6000 feet from the Pompano outfall. The plant dilution (D_p) necessary to reduce the initial concentration of bacteria to 1000 T.C./100 ml at a given distance from the outfall can be calculated from:

$$D_p = \frac{1000 \text{ (T.C./100 ml)}}{Q.D_t.e^{-\lambda d/v}} \qquad (28)$$

where Q = Initial concentration of bacteria (T.C./100 ml)

D_t = Total dilution (from Table 24)

$$\lambda = \begin{cases} .31 & \text{(winter die-off)} \\ 1.55 & \text{(summer die-off)} \end{cases}$$

d = distance from outfall (feet)

v = current speed (feet/hr)

The percent treatment (% T) for coliform removal in the sewage plant necessary to produce the calculated plant dilution is given by:

$$\% \, T = (1 - D_p)100 \qquad (29)$$

In order to determine the plant dilution and percent treatment of the Pompano outfall system necessary to restrict pollution to 6000 feet from the outfall we use the following values:

$Q = 3 \times 10^7$ T.C./100 ml

$D_t = 2.53 \times 10^{-3}$

$\lambda = .31$ (winter)

$ 1.55$ (summer)

$d = 6000$ feet

$$v = 0.2 \text{ knots} = 1216 \text{ feet/hr}$$

The current speed represents the mean speed of the west component, determined from the current meter records. Using equation (28) and (29) the plant dilution and percent treatment for the Pompano outfall is for:

No die-off $D_p = 1.32 \times 10^{-2}$

$\% T = 98.68\%$

Winter die-off $D_p = 5.95 \times 10^{-2}$

$\% T = 94.56\%$

Summer die-off $D_p = 2.94 \times 10^{-1}$

$\% T = 70.6\%$

if one used the mean current speed of the more predominate north-south currents of 0.5 the plant dilution and percent treatment become:

No die-off $D_p = 1.32 \times 10^{-2}$

$\% T = 98.68\%$

Winter die-off $D_p = 2.44 \times 10^{-2}$

$\% T = 97.56\%$

Summer die-off $D_p = 2.94 \times 10^{-1}$

$\% T = 70.6\%$

If the Pompano outfall system increased the pumping rate 3 times, then as was shown by the dilution contours, the result could be explained in two ways: 1) the initial concentration would increase by 3, thus increasing by 3 all the values in the plume (diffusion theory); 2) the cross plume standard deviation would increase by 3, thereby increasing 3-fold the width of the plume (stream flow theory).

In order to see the effect of increasing the pumping rate on plant dilution and percent treatment one can simply increase the initial concentration by an equivalent amount and perform the calculations. The result of increasing the Pompano outfall pumping rate 3-fold is as follows:

for 0.5 knot current

No die-off $D_p = 4.4 \times 10^{-3}$

$\% T = 99.56\%$

Winter die-off $D_p = 8.1 \times 10^{-3}$

$\% T = 99.19\%$

Summer die-off $D_p = 9.8 \times 10^{-2}$
$\% T = 90.20\%$

for 0.2 knot current

No die-off $D_p = 4.4 \times 10^{-3}$
$\% T = 99.56\%$

Winter die-off $D_p = 1.98 \times 10^{-2}$
$\% T = 99.02\%$

Summer die-off $D_p = 10.2$
$\% T =$ None

The Pompano outfall is discharging at a water depth of 90 feet. This is the point on the Continental Shelf where the slope of the bottom topography steepens (break in shelf). The 90 foot depth is similar in this respect all along the Southeast Florida Shelf. Since the western edge of the Florida Current meanders laterally across the break in shelf then the variations and distributions of the oceanographic features such as currents, temperature and salinity should be similar. Thus, any outfall discharging at the 90 foot water depth would be expected to have a similar total dilution and bacteria die-off as Pompano. Table 19 shows 6 outfalls that are either in operation or soon to be completed, that discharge in a water depth of 90 feet. The plant dilution and percent treatment necessary to prevent water from the respective outfalls with bacteria counts greater than the state standard from coming closer than 1000 feet from shore can be calculated based on the techniques used in Pompano. These calculations using the mean speed of 0.5 knots for the predominate currents are presented in Tables 25, 26, and 27. The initial bacteria concentration of the outfalls shown in the above tables is determined as some product of the initial bacteria concentration of Pompano (3×10^7 T.C./100 ml). The product is determined as the ratio of the pumping rate of the outfall in question to that of Pompano (from Table 19). The total dilution (D_t) values were taken from Table 24 based on the values for d from column 4. The values for die-off were computed from $e^{-\lambda d/v}$. Plant dilution (D_p) and percent treatment (% T) were computed with equations (28) and (29).

This approach represents a conservative method of estimating plant dilution and percent treatment in terms of bacteria only. It is an empirical approach relying on real data and not on a model which may only sometimes apply. It is conservative for it is based on a 97.7% confidence limit that the actual total dilutions will never be greater than the values given in Table 24 and shown in Figure 151. It is conservative in that the total dilution values are for the

TABLE 25

PLANT DILUTION AND PERCENT TREATMENT

NO DIE-OFF

CITY	(FT) PIPE LENGTH	(MGD) PUMPING RATE	d(FT) DISTANCE FROM OUTFALL	(T.C./100 ml) Q	D_t	D_p	% T
Pompano	7,400	2.7	6,000	3×10^7	2.53×10^{-3}	1.32×10^{-2}	98.68
Boca Raton*	5,200	2.3	4,000	2.55×10^7	3.33×10^{-3}	1.18×10^{-2}	98.82
Hollywood	10,235	11	9,200	1.22×10^8	1.89×10^{-3}	4.34×10^{-3}	99.56
Delray Beach	5,100	2.0	4,000	2.22×10^7	3.33×10^{-3}	1.35×10^{-2}	98.65
Lake Worth	5,200	3.0	4,000	3.33×10^7	3.33×10^{-3}	9.0×10^{-3}	99.10
Palm Beach	5,790	6.0	4,800	6.66×10^7	2.94×10^{-3}	5.1×10^{-3}	99.49

*Under Construction

TABLE 26

PLANT DILUTION AND PERCENT TREATMENT

WINTER DIE-OFF

CITY	(FT) PIPE LENGTH	(MGD) PUMPING RATE	c (FT) DISTANCE FROM OUTFALL	(T.C./100ml) Q	D_t	DIE-OFF	D_p	% T
Pompano	7,400	2.7	6,000	$3x10^7$	$2.53x10^{-3}$	$5.38x10^{-1}$	$2.44x10^{-2}$	97.56
Boca Raton*	5,200	2.3	4,000	$2.55x10^7$	$3.33x10^{-3}$	$6.64x10^{-1}$	$1.78x10^{-2}$	98.22
Holly-wood	10,235	11	9,200	$1.22x10^8$	1.89x10	$3.91x10^{-1}$	$1.11x10^{-2}$	98.89
Delray Beach	5,100	2.0	4,000	$2.22x10^7$	3.33x10	$6.64x10^{-1}$	$2.04x10^{-2}$	97.96
Lake Worth	5,200	3.0	4,000	$3.33x10^7$	3.33x10	$6.64x10^{-1}$	$1.35x10^{-2}$	98.65
Palm Beach	5,790	6.0	4,800	$6.66x10^7$	2.94x10	$6.13x10^{-1}$	$8.32x10^{-3}$	99.17

*Under Construction

TABLE 27

PLANT DILUTION AND PERCENT TREATMENT

SUMMER DIE-OFF

CITY	(FT) PIPE LENGTH	(MGD) PUMPING RATE	d (FT) DISTANCE FROM OUTFALL	(T.C./100ml) Q	D_t	DIE-OFF	D_p	% T
Pompano	7,400	2.7	6,000	$3x10^7$	$2.53x10^{-3}$	$4.50x10^{-2}$	$2.94x10^{-1}$	70.60
Boca Raton*	5,200	2.3	4,000	$2.55x10^7$	$3.33x10^{-3}$	$1.30x10^{-1}$	$9.08x10^{-2}$	90.92
Hollywood	10,235	11	9,200	$1.22x10^8$	$1.89x10^{-3}$	$9.09x10^{-3}$	$4.78x10^{-1}$	52.20
Delray Beach	5,100	2.0	4,000	$2.22x10^7$	$3.33x10^{-3}$	$1.30x10^{-1}$	$1.04x10^{-1}$	89.60
Lake Worth	5,200	3.0	4,000	$3.33x10^7$	$3.33x10^{-3}$	$1.30x10^{-1}$	$6.94x10^{-2}$	93.06
Palm Beach	5,790	6.0	4,800	$6.66x10^7$	$2.94x10^{-3}$	$8.63x10^{-2}$	$5.91x10^{-2}$	94.09

*Under Construction

peak concentrations in the effluent plume. It is conservative in that it is a method to prevent pollution of the bathing waters from occuring at any time within the confidence limits. It is also conservative in that a 0.50 knot current was used in computing the time of travel for bacteria die-off. If a 0.2 knot current is used then, during the summer (85°F water temperature) no plant treatment would be necessary at Pompano, die-off is large enough to kill the bacteria. The values given in Table 19 are not up to date and the pumping rates are daily averages, not peaks. In this respect the approach is not as conservative.

The remaining outfalls from Table 19 that do not discharge in 90 feet cannot be estimated by this method. This is because the values for total dilution given in Table 24 will not apply to the shallower depths. Field surveys to determine bacteria concentrations and total dilution-vs-distance are greatly needed for these outfalls and the outfalls discharging in 90 feet of water.

CONCLUSIONS

Many communities along the southeast Florida coast are using ocean outfalls to dispose of human effluent. These communities are employing little if any treatment. They rely on the receiving shelf waters to dilute the wastes and kill off the bacteria and viruses. After leaving the outfall pipe the effluent being less dense than the surrounding water will rise to the surface forming a "boil". Once in the surface the effluent stretches out in the form of a "plume". If the combined effects of current speed and stability are great enough the effluent will be prevented from rising to the surface and will be mixed with the shelf water at some subsurface depth, thus, decreasing the likelihood of it coming ashore. The effluent undergoes large initial dilutions ranging from 70 to 250:1 on rising to the surface from 90 feet due to mixing and dispersion with the shelf water. The horizontal dilutions occuring in the plume are approximately an order of magnitude smaller than the initial dilutions. The product of these two dilutions is the total dilution from the sewage plant to the peak concentration in the plume.

A diffusion model and stream line model were investigated. The stream line model was not used in the analysis because it produces no downstream dilution and the plume approaches a fixed width and does not continue to spread. The diffusion model was used to keep track of the fluorometry data and provides the basis for our analysis. The data were analyzed in two ways: 1) Sample fit analysis where the cross plume standard deviation and total dilution was determined from the traverse data; 2) Gaussian fit analysis where the standard deviation and total dilution were determined from a Gaussian curve fitted to the traverse data. In general the two approaches are in good agreement, with the sample fit analysis giving slightly higher peak concentrations and the Gaussian fit analysis larger cross plume standard deviations. The longer the fluorometry experiment and the greater the amount of data then the agreement becomes better.

The Pompano fluorometry experiments were reduced to dilution contours showing the line of 1000 T.C./100 ml using no die-off, winter die-off, summer die-off rates and with increasing the pumping rate 3-fold. Increasing the pumping rate will either increase the initial concentration and extend the effluent plume or increase the standard deviation and widen the plume depending on whether a diffusion or stream line view is taken. The dilution contours show a large area of water with bacteria concentrations greater than the state standard of 1000 T.C./100 ml for bathing waters. Winter die-off has very little effect on the dilution contours. Summer die-off reduces the pollution to a small area around the outfall. A large number of the dilution contours show a shoreward component whose direction is dependent upon the strength of the onshore wind. Current meter records also show a shoreward component with a mean of 0.2 knots that can last several days. Drift cards dropped in the region of the Pompano outfall have come ashore at many sites along the Florida east coast.

A composite log-log plot of total dilution-vs-downstream distance for all the fluorometry experiments reveals that mixing and dispersion of the effluent with shelf water will not reduce an initial concentration of bacteria of 3×10^7 T.C./100 ml to the safe bathing standard in 14,000 feet from the outfall. A second degree polynomial was fitted to this plot yielding an equation for predicting total dilution with distance. A line two standard error of regressions away from the data fit was plotted. The equation for this line enables the total dilution to be predicted with 97.7% confidence that the actual total dilution will not be greater (worse from a pollution standpoint) than predicted. These predicted values were tabulated for every 500 feet from the Pompano Outfall.

Assuming a current speed of 0.5 knots and a distance of 7,400 feet from the Pompano Outfall, bacteria die-off will account for a reduction of 4.77×10^{-1} of the initial concentration in the winter. This represents a total reduction due to die-off and total dilution of 1.04×10^{-3} and leaves a bacteria count of 31,200 T.C./100 ml. At 15,000 feet the total reduction will yield bacteria counts of 14,100 T.C./100 ml for the winter. It takes a distance of 30,000 feet from the outfall before the total reduction of the bacteria reaches the state standard.

Total dilution and bacteria die-off are insufficient in reducing the initial concentration of bacteria to safe bathing water standards within 7500 feet, which is the distance from the outfall to shore. Therefore, pollution of the bathing waters from the Pompano Outfall is a marked possibility, especially in the winter when high coliform counts are found 5 nautical miles from the outfall. In order to insure that the bathing waters are not polluted by high bacteria concentrations, the effluent should be treated for coliform removal in the sewage plant in order to restrict the polluted effluent plume to a distance of 6000 feet from the outfall. A formula was created from which the plant dilution and percent treatment necessary to accomplish this can be calculated. The recommended treatment for bacteria kills in the Pompano Outfall is 97.56% for winter (75°F water temperature) and 70.60% during the summer (85°F water temperature). It should be possible to calculate the plant dilution and percent treatment for any outfall on the southeast Florida coast that discharges in 90 feet of water, using the tables and formulas derived for Pompano. A table of plant dilution and percent treatment for all the outfalls in 90 feet of water is shown in the text. The treatment recommended is similar to that of Pompano. The large outfall systems of the Miami area are discharging in water depths less than 90 feet so that Pompano total dilutions will not apply. The total dilution of effluent from these outfalls will have less effect on reducing the initial concentration of bacteria than Pompano.

Fluorometry experiments should be conducted on all the outfall systems of southeast Florida in order to determine the actual values of dilution and plant treatment necessary to protect the bathing waters.

The only pollution indicator from the Pompano Outfall found to be significant is the number of total coliforms/100 ml in the effluent plume. Strong currents at the point of discharge prevent a large build-up of organic material that would decrease dissolved oxygen, and increase nutrient concentrations and turbidity. The concentration of dissolved oxygen, phosphate and nitrate decrease to background a short distance from the outfall. However, the strong currents are responsible for extending the polluted effluent plume to large distances from the outfall by decreasing the die-off time.

The Miami outfalls are discharging approximately one mile inside of the edge of the Continental Shelf. These outfalls have greater pumping rates than Pompano, water depths are less and currents are slower. Under these conditions an organic buildup may very likely be taking place.

The approach taken in computing plant dilution and percent treatment for outfalls discharging at water depths of 90 feet is conservative for it is based on preventing the occurance of pollution in the bathing waters with a 97.7% confidence.

EVALUATION IN TERMS OF WATER QUALITY STANDARDS

Class III waters are those which are to be used for recreational purposes, including such body contact activities as swimming and water skiing; and for the maintenance of a well-balanced fish and wildlife population. All coastal and beach waters, including off-shore waters, not otherwise classified shall be classified as Class III waters. The following are the state classification criteria for Class III waters:

1) Sewage, industrial wastes, or other wastes shall be effectively treated by the latest modern technological advances as approved by the regulatory agency.

2) The pH of receiving waters shall not be caused to vary more than one (1.0) unit above or below normal pH of the waters. The lower limit shall not be less than six (6.0), not the upper limit more than eight and one-half (8.5). In cases where pH values may differ from these limits due to natural background or outside causes, approval of the regulatory agency shall be secured prior to introducing such material in waters of the state.

3) The dissolved oxygen concentration shall not be artificially depressed below four (4.0) ppm, unless background information indicates the prior existence of lower values under unpolluted conditions. In such cases, lower limits may be utilized after approval by the regulatory authority.

4) The coliform bacteria group shall not exceed 1,000 per 100 ml as a monthly average, (either MPN or MF counts). It shall not exceed this number of more than 20% of the samples examined during any month; nor shall it exceed 2,400 per 100 ml (MPN or MF count) on any one day. This criteria shall apply only to waters used for body contact activities.

5) Class III waters shall be free from substances attributable to municipal, industrial, agricultural, or other discharges in concentrations or combinations which are toxic or harmful to human, animal, or aquatic life.

6) Class III waters shall be free from dele-

terious materials attributable to municipal, industrial, agricultural, or other discharges producing color, odor, or other conditions in such a degree as to create a nuisance.

7) The turbidity shall not exceed fifty (50) Jackson units as related to standard candle turbidimeter measurements above background.

8) The temperature shall not be increased so as to cause any damage or harm to the aquatic life or vegetation of the receiving waters, or interfere with any beneficial use assigned to such waters.

The data from this study indicate that state water quality criteria are not exceeded with regard to pH, dissolved oxygen concentration, turbidity, temperature, or deleterious material in quantities sufficient to be a nuisance in the area of man/water contact. Marginal conditions exist regarding the presence of floatable materials.

Along with a limited amount of aesthetic pollution the findings indicate the presence of certain biological indicators of pollution in the vicinity of the sludge pile at the outfall terminus. Potential pollution of coastal waters exists in the man/water contact zone whenever the downstream plume intersects with surf waters causing a monthly average coliform concentration in excess of 1000 MPN/100 ml.

ENGINEERING IMPLICATIONS

If the use of ocean outfalls as a method of waste disposal is to continue, the engineer is confronted with finding a solution to the potential beach water contamination due to floatable solids and bacteriological indices.

Experimentation with comminution in series following coarse and fine screening may produce a satisfactory particle size to preclude the event of floatables breaking across the currents and intersecting the beach surf. Primary treatment with effective removal of floatable solids including grease would insure a more dependable everyday method when practiced in parallel with series comminution for normal maintenance by-pass of the primary unit.

The "State of the Art" of reliable and continuous disinfection of sewage to reduce bacterial loading on a receiving water provides empirical data as to the dosage and contact time to provide residuals capable of 98 to 99.8 percent destruction of coliforms.

In assessing bacterial removal efficiency following varying degrees of treatment, there appears to be a major discrepancy between the predictive level and the accomplished. It will be necessary for the engineer to re-evaluate current chlorination practices which merely control odor, and to develop new methods which will lead to effective bacterial destruction.

The oceanographic and marine waste disposal sections of this report indicate a semi-permanent stratification layer between 200 to 300 feet water depth. It is therefore important that existing and planned outfalls of southeast Florida be investigated as to the feasibility of discharging within this depth range. The combination of greater stratification, increased vertical distance, stronger magnitude currents will aid in mixing effluent beneath the surface. At times when the effluent does reach the surface the increased distance to shore will further aid in reducing effluent concentrations to bathing water standards before intersecting the beach.

SECTION VIII

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Further information relating to this project may be obtained by contacting Mr. Lawrence D. Lukin, Principal Investigator, Florida Ocean Sciences Institute, Inc., 1605 S. E. Third Court, Deerfield Beach, Florida 33441.

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SECTION IX

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